STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
DIVISION OF THE
STATE GEOLOGICAL SURVEY
M. M. LEIGHTON, *Chief*

REPORT OF INVESTIGATIONS—NO. 31

BRIQUETTING ILLINOIS COALS WITHOUT A BINDER BY COMPRESSION AND BY IMPACT

A Progress Report of a Laboratory Investigation

BY

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PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS
1933

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(2464—15468)

Contents

Illustrations

Tables

BRIQUETTING ILLINOIS COALS WITHOUT A BINDER BY COMPRESSION AND BY IMPACT

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By R. J. Piersol

CHAPTER I

Summary

The briquetting of fine sizes of bituminous coal has long been regarded as a possible means of extending the market for this coal if it could be accomplished without increasing the objectionable features of the coal and without adding greatly to its cost. Such fuel would probably find its best market among discriminating users of domestic coal seeking a moderate priced but clean fuel. The general excess of fine coal over the market demand has always been an important handicap of the bituminous coal mining industry, a condition greatly accentuated by the recent rapid increase in mechanization. The preparation and marketing of satisfactory briquets would contribute to a correction of this condition.

Numerous more or less successful attempts, on both laboratory and commercial scale, have been made to prepare briquets using various kinds of binders, which, however, not only add to the cost of the raw material but likewise commonly increase the smokiness of the fuel. It appeared desirable therefore to investigate the possibility of preparing briquets from Illinois coal by some sort of compaction without the use of a binder. The present report presents the progress that has been made in such an exploratory investigation using continuous pressure in one set of tests and impaction in the other, these being the two most obvious means by which briquets might be made without a binder.

Examination of the literature of briquetting and a brief series of tests described in the report indicated the probability that a satisfactory briquet could not readily be made by compression by the methods employed either previously as reported in the literature or by those used in the present series

of tests, the length of time required for the formation of each briquet being the most important obstacle to the success of the method. On the other hand tests of the impaction method gave promise of success; this methods was, therefore, more thoroughly investigated.

The impaction tests consisted first of impaction with two blows upon coal preheated in the die and then upon coal preheated in an oven. The results indicated that the briquets of satisfactory quality with respect to hardness, friability, and general resistance to fracture and cleanliness can be made by the double-impact method when the coal is heated in the die, but less readily when the coal is preheated in an oven. On the other hand, tests using one blow upon preheated coal indicated that under certain definite conditions good briquets could be made from coal heated either in the die or in the oven by this single-impact process. Because of the great advantage of this process over any other that approached success it was selected as the most suitable to meet commercial conditions.

The set of conditions recommended as of greatest promise of usefulness required 40 to 45 grams of coal crushed to pass a 1/4 or 3/8-inch screen, and an impact equivalent to the drop of a 500-pound weight 4 1/2 feet upon the coal preheated 10 minutes at 300° C. in an oven.[1]

The possibility of making briquets by several variations of the impact method is demonstrated in the case of a fairly wide selection of Illinois coal but it is apparent that the process recommended produces most consistently the most satisfactory briquets as is indicated by the results of certain arbitrarily selected tumbling and shattering tests.

It is planned to continue the investigation, particularly in regard to the effect of ash content of the coal upon the quality of the briquet, the effect of weathering upon the briquets, and in regard to their burning qualities. Tests will be extended likewise to include a larger group of coals and refuse dusts obtained at dedusting plants. It is believed that eventually it will be desirable for the coal industry to inaugurate pilot plant tests.

Introduction

An enlargement of the market for bituminous coal would probably result if clean, hard, low-ash and moderately priced briquets could be prepared from such coal. Since the fine sizes of coal are essential to the preparation of briquets, successful methods of manufacture would probably result in some relief to the pressure exerted upon the industry by the excess of fine coal produced in the mining and cleaning processes. The essential requirements of a satisfactory coal briquet are moderate cost, resistance to breakage in handling and in weathering, and a relatively low ash content. Briquetting to be suc-

[1] 45 grams = 0.1 pound; 300° C. = 572° F.

cessful should in general improve the quality of the fuel, increasing neither the smokiness nor the moisture content.

The present investigation represents attempts, which under certain conditions were successful, to produce in the laboratory a satisfactory briquet that will represent an improvement over the raw fuel in the particulars noted above. Actual cost can be determined only by commercial scale production.

It is planned to apply for patent to protect this process in the interest of the coal industry of Illinois.

ACKNOWLEDGEMENTS

Samples of coal for briquetting tests were furnished by various Illinois coal mining companies and members of the survey staff.

The hydraulic press was used through the courtesy of Professor C. W. Parmelee, Head of Department of Ceramic Engineering, University of Illinois; and the impact machine through the courtesy of Professor M. L. Enger, Head of Department of Theoretical and Applied Mechanics, University of Illinois.

Assistance in the experimental tests was rendered by Mr. J. M. Nash, Physics Assistant, of the Survey. Mr. H. C. Roberts, Physics Assistant, of the Survey, prepared the photographs. Chemical analyses were carried out under the supervision of Dr. O. W. Rees, Analytical Chemist of the Survey.

Dr. G. H. Cady, Senior Geologist, rendered valuable assistance in preparing the manuscript, and Dr. M. M. Leighton, Chief, gave continued support to the investigation.

BRIQUETTING WITH AND WITHOUT A BINDER

It is particularly desirable to prepare briquets without the use of binders because binders add not only to the cost (an average of 72 cents per ton as compared to a total briquetting cost of $1.06 per ton (*48*)[2] but also to the smokiness of the original fuel. For these reasons and because it was believed possible to obtain compaction without the use of a binder, this investigation was limited to experiments in briquetting without a binder.

BRIQUETS BY COMPRESSION AND CARBONIZATION

The carbonization of briquets formed by compression without a binder has in some instances yielded a product representing an improvement over the original fuel. The cost of the process, however, is objectionable, particularly if satisfactory briquets can be made without carbonization. This process was therefore not considered as within the scope of the present investigations although the processes of compression employed in preparing briquets for carbonization are briefly described.

[2] Figures in parentheses refer to articles listed in the bibliography at the end of the report.

POSSIBILITY OF PREPARING BRIQUETS WITHOUT A BINDER

Nature of compaction without a binder.—The possibility that fine sizes of bituminous coal in small amounts might yield to certain conditions of pressure and temperature with proper time control to form a resistant solid mass is suggested by certain attributes of coal. Particularly significant is the plasticity of coal developed under pressure at comparatively low temperatures of about 300° C. Coal is one of the most susceptible of the rocks to earth pressures, the effect of which is to increase its hardness. Furthermore the "bituminous" components of coal, such as waxes and resins which are more or less plastic by nature, if not too greatly changed by the coalification process, might be expected to yield to pressure and possibly to provide binding constituents. In view of these considerations, acknowledged to be more or less speculative, it did not seem unreasonable that conditions could be devised which would yield a firm briquet from at least some varieties of fine coal.

Compression and impact.—With time as one of the factors in compaction it is evident that pressure of two kinds was possible—sustained pressure and suddenly applied pressure. This definitely provided two types of compaction, namely compression and impact. In the case of sustained pressure the time at which different pressures might be applied and the time during which the coal could be heated could be varied. In the case of impact only the time of heating and the amount of impact could be varied. A succession of impacts of the same or different amounts would of course be possible.

Variables involved in the formation of briquets by compression and impact.—The physical conditions involved in the formation of briquets by compression and impact are particularly those represented by variations in time, pressure, and temperature, and the variations in the coal itself, such as size of grain, moisture content, ash content, and the nature and proportion of the banded ingredients—vitrain, clarain, durain, and fusain[3]—the amount of coal compressed, and the shape of the die.

Variations in time are obviously limited by a practical consideration to not more than a few minutes for the formation of a single briquet. Pressure was limited by the capacity of the devices available to 70,000 pounds per square inch but economic considerations in industrial practice might require lower pressures. The range of temperatures of practical value are less than 350° C., since at higher temperatures the coal becomes excessively plastic and decomposes with the evolution of troublesome gases and liquids. It was realized that different results might be obtained by applying the heat to the coal in the die during or before compression and in an oven before compression.

[3] *Vitrain* is the coal composing the bright vitreous or glassy bands—called anthraxylon by Thiessen. *Clarain* is the coal composing the bright but not vitreous bands—called attrital coal by Thiessen. *Durain* is dull coal or "splint coal". It is uncommon in Illinois coals but thin layers of one inch or less are occasionally present particularly in coal No. 6. *Fusain* is "mineral charcoal" or "mother coal".

The size of the fine coal used in making the briquets might vary from powder of 100-mesh or smaller to two-inch coal, since this is the trade limit of fines. In these investigations, however, no tests were made on fines larger than $\frac{1}{4}$-inch mesh and most of the tests were made on fines of this size. The effect of variations in size of grain has not been thoroughly explored.

The effect of variations in moisture content might be considerable since it is not improbable that moisture is responsible for part of the binding action. This effect of this variable was therefore explored to some extent.

Undoubtedly variation in ash content is of great importance in the formation of briquets without a binder. However, as it seemed best to limit the present investigations to coals of average quality, no coals with excessive ash content were used. Eventually it is desirable to determine the permissible limits of ash content for the formation of satisfactory briquets. It should be realized, however, that ash is no more desirable in a briquet than in any kind of fuel and that clean coal is the essential raw material for the formation of a good briquet.

Undoubtedly the different banded ingredients of the same coal will be affected differently by the briquetting process. Fusain particularly, since it is low in bituminous constituents and possesses little binding capacity, would be expected to yield a weak briquet or none at all under the same conditions under which clarain or vitrain would yield a strong briquet. Illinois coals contain only small amounts of durain. It is probable that fines in which fusain has concentrated will compact less readily than those in which there is little fusain.

The quantity of coal used in the briquetting tests might be varied indefinitely. Since, however, most satisfactory combustion behavior is obtained with coal of nut size it seemed logical to consider that briquets within the range of nut sizes would prove most satisfactory. This gave a range between about two inches and three-eighths of an inch as the most favorable sizes for experimentation. Within this approximate range tests were made on briquets of several sizes, the largest $2\frac{1}{2}$ inches in diameter and the smallest one-half inch in diameter, and on different weights of coal ranging from 2.5 to 250 grams.

COALS USED IN THE INVESTIGATION

The coals used in the briquetting test came from different mines and seams and represent different sizes and quality of coal (Table 1).

Table 1—*Source, size, and condition of coal received for briquetting tests*

County	Seam	Size	Condition	Sample	Supplied by
Washington (a)*	6	Various	Natural	Column	Survey.
Sangamon	5	+1¼	Natural	Car or tipple	Company.
Jackson	6	+1¼	Natural	Car or tipple	Company.
Franklin (c)	6	+1¼	Natural	Car or tipple	Company.
Macoupin (a)	6	⅜	Natural	Car or tipple	Company.
Will	2	⅜	Natural	Car or tipple	Company.
Franklin (b)	6	⅜	Natural	Car or tipple	Company.
Franklin (a)	6	⅜	Natural	Car or tipple	Company.
Williamson (a)	6	⅜	Natural	Car or tipple	Company.
Perry (a)	6	⅜	Natural	Car or tipple	Company.
Saline	5	⅜	Natural	Car or tipple	Company.
Perry (b)	6	⅜	Natural	Car or tipple	Company.
Franklin (a)	6	⅜	Natural	Car or tipple	Company.
St. Clair (a)	6	¼	Floated on 1.3 gravity	Face	Survey.
Montgomery	6	¼	Floated on 1.3 gravity	Face	Survey.
Williamson (b)	6	¼	Floated on 1.3 gravity	Face	Survey.
Washington (b)	6	¼	Floated on 1.3 gravity	Face	Survey.
Perry (c)	6	¼	Floated on 1.3 gravity	Face	Survey.
St. Clair (b)	6	¼	Floated on 1.3 gravity	Face	Survey.
Macoupin (b)	6	¼	Floated on 1.3 gravity	Face	Survey.
Randolph	6	¼	Floated on 1.3 gravity	Face	Survey.
Franklin (b)	6	¼	Floated on 1.3 gravity	Car or tipple	Company.
Perry (b)	6	¼	Floated on 1.3 gravity	Car or tipple	Company.
Franklin	6	¼	Floated on 1.3 gravity	Car or tipple	Company.

* Letters in parentheses refer to different mines in the same county.

The coal was in some instances used in the sizes supplied and in other cases was crushed to about ¼-inch or less.

CHAPTER II—BRIQUETTING ILLINOIS COALS BY COMPRESSION WITHOUT AN ARTIFICIAL BINDER

Previous Attempts to Briquet Bituminous Coal by Compression Without an Artificial Binder

The following four attempts to briquet coal for raw fuel and five attempts to briquet coal for subsequent carbonization, in all cases without using a binder, have been described in the literature.

RAW FUEL BRIQUETS WITHOUT A BINDER

Fuel-briquetting investigations jointly by United States Geological Survey and United States Bureau of Mines (48).—From 1904 to 1912, the Fuel Testing Plant of the United States Geological Survey at St. Louis investigated the physical and chemical properties of coal. Tests were made on the briquetting of coal, both with and without binder. Fine, moist coal at steam temperature was formed into 5-gram briquets in a hand press at a pressure of 4000 pounds per square inch. Holmes, who was in charge of the work, stated that "the results were unsatisfactory."

Briquetting investigations of Sweitoslawski, Roga, and Chorazy in Warsaw, Poland (79).—In 1929, Sweitoslawski, Roga, and Chorazy used a hydraulic press to briquet both with and without binder 25-gram samples of coal under various conditions of time, temperature, and pressure. Without binder the time of heating the coal in the press ranged from 30 to 45 minutes. For eight non-coking coals, the optimum temperature range was from 400° to 420° C. At this temperature, the minimum pressure was 5700 pounds per square inch. Briquets made of non-coking coals showed high resistance to tumbling and shattering tests as compared to those made of coking coals. The best size assortment was found to be from less than 12-mesh to coal dust. They concluded that the properties of the finished briquets depend primarily upon the characteristics of the binder, but that when no binder is used, the properties of the finished briquets depend primarily upon the quality of the raw coal and upon the conditions under which the tests were conducted.

Laboratory results indicated that briquets made without binder are stronger mechanically, ignite at low temperature, burn without crumbling, and produce less smoke than briquets made with binder.

In 1930, the same investigators devised three methods for producing a stronger briquet from coking coals at a pressure range of from 2800 to 4300 pounds per square inch. In the first method the coal is heated to the temperature of incipient plasticity, thereby producing briquets having a granular structure; in the second the coal is heated for the necessary length of time at the temperature of greatest plasticity in order to reduce the bituminous matter to the critical proportion; and in the third, the coal is heated at the upper temperature limit of plasticity in order to decrease the time of treatment. Their laboratory test showed that anthracite coals cannot be briquetted at any temperature without the use of binder, even at pressures up to 40,000 pounds per square inch. The strength of briquets of semi-bituminous coals was found to vary directly with their volatile content. All the briquets studied were made in a hydraulic press. This investigation remains in the laboratory stage.

Briquetting tests by Stansfield of the Research Council of Alberta, Canada (73).—In 1931, Stansfield failed in attempts to form briquets without binder in a hand press at 400° C., using coking coal and a mixture of coking coal and lignite.

Briquetting investigations by Levy in Paris, France (57).—In 1932, Levy experimentally briquetted coal without artificial binder in a hydraulic press. The strongest briquets were made at a temperature range of from 430° to 450° C., the strength increasing up to the maximum attainable pressure of 20,000 pounds per square inch. A simultaneous application of heat and pressure for more than five minutes caused a decrease in the mechanical strength. The best assorted sizing of the coal particles was found to be from smaller than 25-mesh to larger than 400-mesh. The mechanical strength decreased as much as 40 per cent for briquets from coal smaller than 400-mesh and as much as 50 per cent for briquets from coal smaller than 8- and larger than 25-mesh. This investigation still remains on a laboratory scale.

BRIQUETS FOR SUBSEQUENT CARBONIZATION

"Pure Coal Briquet" Process by Sutcliffe and Evans in Leigh, England (78).—In 1910, Phillips and Phillips developed a laboratory process for preparing carbonized briquets which was later commercialized by Sutcliffe and Evans at the Leigh Works of Messrs. Sutcliffe, Speakman and Company, under the name of "Pure Coal Briquets." Their process consists of briquetting without binder in a specially developed press a mixture of moist, pulverized coal with 20 per cent of pulverized coke breeze (added to prevent swelling

at time of carbonization) at a pressure of 20,000 pounds per square inch. The resulting briquets are carbonized at temperatures from 600° to 1000° C. in order to give them mechanical strength. These carbonized briquets are said to contain 2 per cent volatile matter, to be easily ignited, to possess a structure similar to coal char, and to burn with a smokeless flame and high radiant heat.

Briquetting tests by Parr at the University of Illinois (69).—In 1912, incidental to his work on low-temperature carbonization, Parr made a few tests on briquetting without binder a moist mixture of fine coal and coke breeze in a hand press with a maximum pressure of 1000 pounds per square inch. Upon subsequent carbonization the moisture was driven out causing the briquets to disintegrate.

Briquetting tests by Dobbelstein in Essen, Germany (16).—In 1914, Dobbelstein made laboratory briquets from a mixture of fine coal and coke breeze at the plastic temperature of about 400° C., using pressures as high as 75,000 pounds per square inch. The briquets were subsequently carbonized.

Delkeskamp Briquetting Process in Berlin, Germany (17).—In 1926, Delkeskamp formed briquets by mixing coal with a colloidal dispersion of coal in water. Tests showed that 6 to 20 per cent colloidal material was needed, depending on the type of coal, in order to briquet it at pressures of 2000 to 4000 pounds per square inch. The resulting briquets were carbonized at either high or low temperatures.

Hardy Briquetting Process in Zandvoorde, Belgium (19).—In 1931, Hardy experimented with briquetting coal in a roll press at temperatures between 350° and 400° C. for subsequent carbonization. This process has not passed to a commercial stage.

SUMMARY OF EARLIER TESTS

These earlier tests achieved only moderate success in making briquets from bituminous coal without a binder. None of the attempts to make a raw fuel briquet reached the commercial stage, and although several processes for preparing briquets for carbonization passed into the commercial stage, the briquets previous to carbonization are weak and deteriorate rapidly. In all instances briquets for carbonization were compressed in a press, and were made from moist coal, or moist coal and coke breeze, the moisture acting as a temporary bond. Carbonization is necessary for permanent strength. In general, the tests were unsystematic in their exploration of the possibilities residing in variation in time, pressure, temperature, and various sizes of coal and briquets.

Briquetting Illinois Coals by Compression Without Binder

The attempts made to briquet Illinois coals without a binder by compression were partially successful but the conditions under which compaction was possible were such as to make the method unsuitable for industrial usage. Certain facts revealed by the investigation of this process are significant with respect to the process of briquetting by impaction, described in Chapter III.

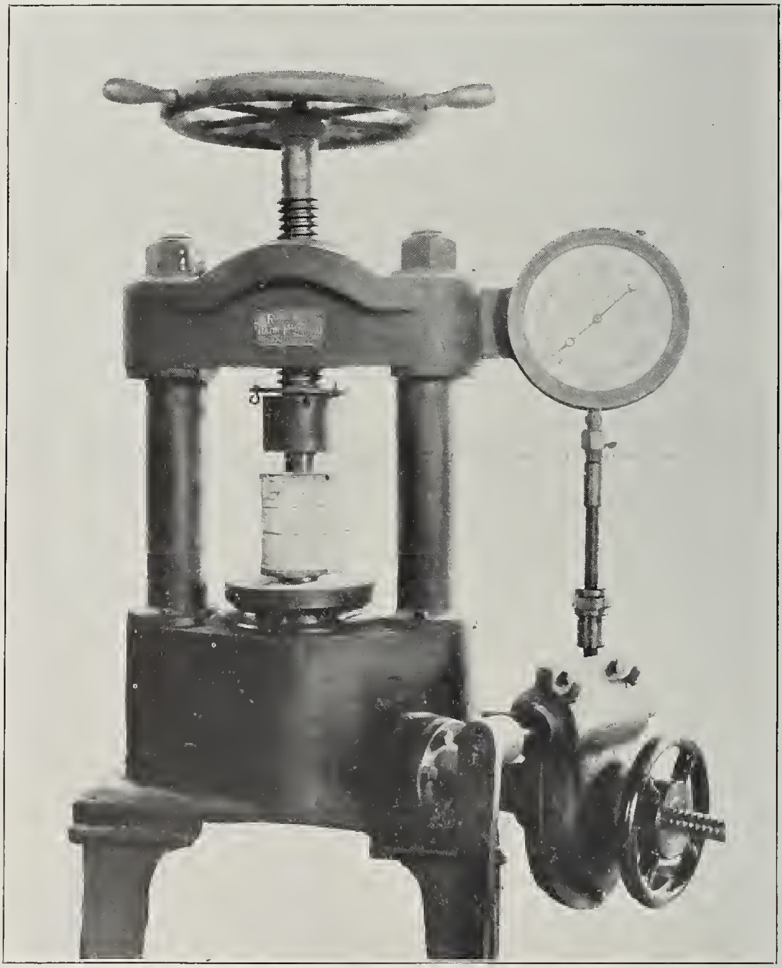

Fig. 1.—Press used for forming briquets by compression.

EQUIPMENT USED AND PROCEDURE

In the study of briquetting coal by compression in a hydraulic press, practically the same equipment and procedure was adopted as has been used by previous investigators *(16, 48, 57, 69, 73, 79.)*

HYDRAULIC PRESS

A 50,000-pound, hand operated, Riehle hydralic press was used in compression experiments, the pressure being applied upon the bottom plate (Fig. 1). The pounds per square inch pressure applied to a briquet is determined by dividing the total pressure by the cross-sectional area of the briquet.

COMPACTION DIE

A spool-shaped steel die of the type shown in figure 2 was used to form briquets 1½ inches in diameter. The die is made of cold rolled steel, No. 2320 S. A. E., 3.5 per cent nickel. The auxiliary cylinder (A) forms the contacting member between the upper plate of the hydraulic press and the top plunger (B). The fine coal is compressed in the space (C) which is surrounded by the sleeve (D), the movable top plunger and the fixed bottom plunger (E) which rests on the lower plate of the hydraulic press. The plungers and inner sleeve are surrounded by an outer sleeve (F) with flanges (G). This spool is wound with heating coil (H), 20 feet of No. 19 resistance wire, which is covered with an asbestos jacket. The maximum temperature used was 425° C., although the die has an attainable temperature of 600° C. In the lower part of the outer sleeve there is an opening (I) within which a thermocouple may be inserted to measure the temperature of the die. The two plungers in contact with the coal have ends so formed as to give the desired shape to the briquet. All the dies constructed are 6 inches high, although sleeves and plungers of various sizes were used in the compression of coal briquets ranging from ½ inch to 1½ inches in diameter.

PREPARATION OF COAL

Size.—The most desirable size of coal for briquetting was found to be smaller than 4-mesh. Coal less than ½ inch in size was reduced to less than 4-mesh by putting it through rolls. Larger size coal was first put through a crusher which reduced it to approximately ½ inch, and then through rolls.

Moisture Control.—Samples were reduced to 2-pound lots and stored in glass jars when constancy of various specific percentages of moisture was required. For experiments at room moisture, the samples were air dried and then stored in paper sacks. In some instances, fine coal was submerged in water to alter experimental conditions. For percentages of moisture less than room moisture the coal was oven dried at 110° C. until it reached the desired value.

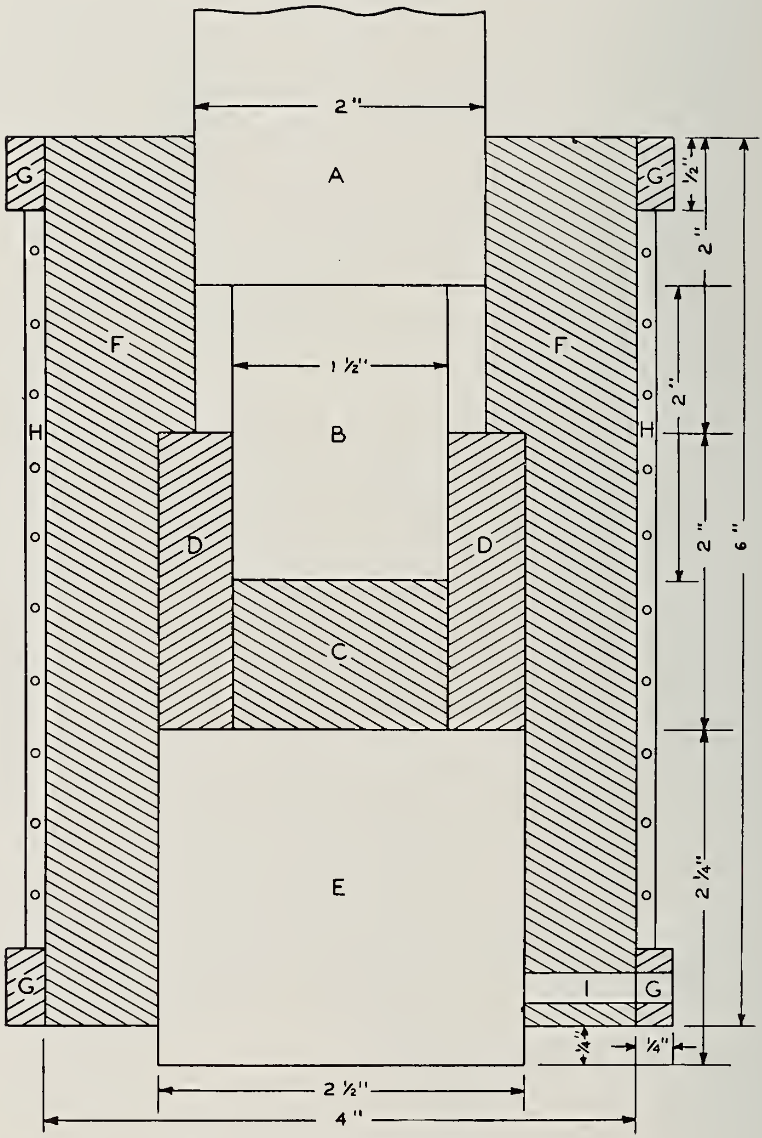

FIG. 2.—Diagram of Compaction Die.

A Auxiliary cylinder
B Top plunger
C Briquet space
D Inner sleeve
E Bottom plunger
F Outer sleeve
G Flange
H Heating coil
I Thermocouple opening

Method of heating coal.—In all instances the coal was heated in the compaction die which had been previously heated to the desired temperature. In certain instances the briquet was formed by the immediate application of pressure, in others the coal was preheated in the die for definite lengths of time before the pressure was applied. The time of compression is the period during which the coal is subjected simultaneously to temperature and pressure.

The temperature of the die was measured by inserting a chromel-alumel thermocouple into the hole in the base of the die so that the junction of the thermocouple was in contact with the bottom plunger. The die is of sufficient heat capacity to insure constancy of temperature. The thermocouple was calibrated against a standard thermocouple every two months during the investigation.

Temperature distribution.—Experimental determination of the temperature gradient of the coal within the die was accomplished as follows: The die was heated and maintained at a constant temperature of 300° C. The same amount of coal (45 grams) was inserted as was used in making a briquet and the bulb of a mercury thermometer was placed in the center of the coal, making it possible to measure the rate of temperature change at this position in the coal. At the end of 30 minutes the temperature at the center of the coal was the same as the temperature of the die. At the end of 45 minutes, the temperature of the coal increased to 330° C. and remained at this temperature throughout the period of observation.

RANGE OF VARIABLES

In the investigation of briquetting by compression, unheated coal, coal heated in the die simultaneously to the application of pressure, and coal preheated in the die prior to the application of pressure, were used. Pressure was employed varying from 1,000 to 70,000 pounds per square inch, temperatures from 0 to 370° C., and time from 3 to 60 minutes. The moisture content of the coal before preheating was approximately 4 per cent with the exception of coal reduced to 0 per cent moisture by heating at 110° C. for one hour. The dies used were two sizes, ½ and 1½ inches in diameter.

PRELIMINARY TESTS

Procedure and results.—The preliminary tests consisted of thirteen trials with Washington County No. 6 coal. Thirty-seven grams of coal containing 4 per cent moisture was used at temperatures varying from 25° to 380° C., with two trials at a pressure of 565 pounds per square inch, one trial at 1,700 pounds, and the remainder at 28,200 pounds, with a spherical die 1½ inches in diameter. The time varied from 5 to 45 minutes. The result was four poor briquets at 28,200 pounds pressure, at temperatures varying from 216° to 370° C., and time varying from 15 to 45 minutes. Mechanical difficulties or explosions attended the formation of two of these briquets. Extrusion or mechanical difficulties also accompanied three unsuccessful trials.

The preliminary tests, although they did not result in the formation of satisfactory briquets, at least indicated the nature of certain peculiar phenomena accompanying the tests, such as the explosive nature of the compacted coal, and the development of extreme plasticity. They also suggested lines of further investigation with respect to modification of the conditions originally imposed, such as the effect of preheating, variations in time up to one hour under various conditions of temperature and pressure, the effect of the size of the coal, and the effect of extrusion of fluid material. The preliminary tests likewise indicated the desirability of determining the relationship between temperature, pressure, and the development of plasticity and also the amount of internal pressure developed within the briquets. A second series of tests and experiments of an exploratory character was therefore carried out along the lines indicated.

FURTHER TESTS

Plasticity curve for coal.—Since it was apparent from the preliminary tests that coal under the conditions imposed developed plasticity and that if compaction took place it would probably be dependent upon this developed plasticity, a series of plasticity determinations as a basis for an incipient plasticity curve was desirable. By such a curve the lower limits of temperature and pressure at which briquets might be formed could be determined, provided plasticity was the controlling factor and provided the coals used in the determination upon which the curve was based were of average character.

Washington County coal obtained from a column which had been kept in cold storage for about 18 months was used. Since analyses of similar columns similarly stored showed little or no deterioration as a result of storage, it is believed that the coal was essentially equivalent to freshly mined coal. The plasticity tests were run in two sets—one with the 1½-inch die (37 and 42 grams) of which there were 48 trials, and one with the ½-inch die (2.5 grams) consisting of 21 trials. For a series of specific pressures (at 1,000 pounds, 2,500 pounds, 5,000 pounds, and thence at 5,000 pound intervals to 30,000 pounds for the 1½-inch briquet, and at 2,000, 3,000, 4,000, 5,000, 10,000, 12,000, 25,000, 30,000, 35,000, 40,000, 45,000, 50,000, 60,000, and 70,000 pounds for the ½-inch briquet) briquets were made at varying temperatures from 0° C. to 350° C. for the ½-inch briquet, and from 160° C. to 360° C. for the 1½-inch briquet. The trials resulted in 17 1½-inch briquets varying from good to poor, only one being good, and 13 medium or poor ½-inch briquets. Briquets were made more successfully in the small than in the large die, with which mechanical difficulties commonly developed (6 cases out of 48). The criterion for the formation of a briquet was simply that it remained whole when pressed out of the die. In most instances, as noted above, the briquet was medium or poor in quality. By plotting on a temperature-pressure diagram (Fig. 3) the points at which briquets were formed, a fairly straight-line relationship is suggested, particularly by the points representing the ½-inch briquet. The graph suggests that at pressures of 60,000 to 70,000 pounds per square inch coal is plastic at low temperature

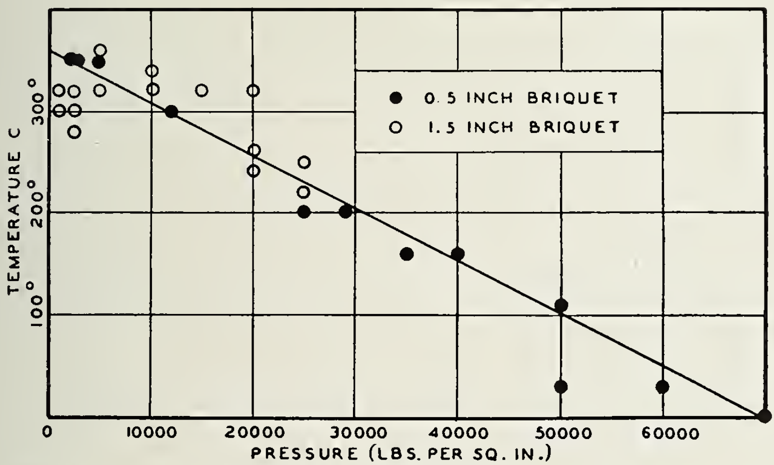

FIG. 3.—Graph showing relation between minimum pressures and temperature at which sufficient plasticity occurred to form briquets.

and, on the other hand, that plasticity develops at atmospheric pressure at temperatures of about 360° C. The results for both sets of tests fall essentially on the same curve indicating that the pressure in pounds per square inch required for briquetting by compression is independent of both cross-sectional area and volume of the briquet in this range of sizes, which is 0.065 to 1.77 cubic inches, or a ratio of 1 to 27.

The value of these tests lies in the fact that they demonstrate that large pressures are not necessary for compaction at temperatures above 300° C., provided the compaction can correctly be attributed to the development of plasticity, the thesis upon which the investigation proceeded.

INTERNAL PRESSURES DEVELOPED IN COMPRESSED COAL

In the preliminary and plasticity tests it was observed that high internal pressures, increasing with the temperatures, above 110° C. became evident in briquets when the external pressure was suddenly released. It appeared probable that this sudden release of internal pressure, which was frequently of explosive violence, was responsible for failure of some of the briquets. It seemed desirable, therefore, to measure this internal pressure as a basis for determining the force necessary to overcome it. Eight tests were run on Washington County No. 6 coal. First an external pressure of 30,000 pounds per square inch was applied to 37 grams of coal in a 1½-inch spherical die, at temperatures varying from 125° to 370° C. The pressure was applied for 4 to 22 minutes, increasing with the temperature. The pressure was then suddenly reduced to between 500 and 1,000 pounds per square inch permitting internal pressure to be released without explosive violence. The hydraulic ram was set at a fixed position and the expansion of the briquet forced the oil to flow against the diaphram of the gauge, thereby registering the developed

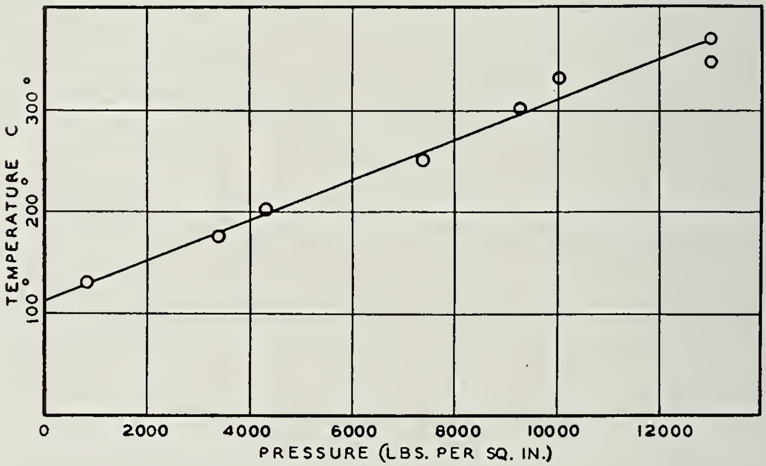

FIG. 4.—Graph showing relation between temperature and magnitude of internal pressure.

pressure (Fig. 1). The internal pressure then developed rose from 800 pounds per square inch for coal heated to 125° C. to 13,000 pounds for coal heated to 345° C. and to 370° C. An approximate straight-line relationship was found to exist between temperature and internal pressure (Fig. 4). It is apparent, therefore, that the formation of briquets by compression at temperatures of about 300° C. probably requires, in order to prevent disruption by explosion, confining pressure for at least a short period in the order of 10,000 pounds. It was found moreover that not only gases but also liquids were extruded as a result of the sudden development of internal pressures and further tests indicated that confining pressures not only prevented the extrusion of these materials but tended to produce a stronger briquet. The length of time that the confining pressure must be maintained increased with the temperature at which original compression was applied.

Since the plunger which compressed the coal had a freedom of movement greater than the thermal expansion of the coal, it is believed that the pressure developed is due to some other cause, such as the evolved gases.

BRIQUETTING BY COMPRESSION AFTER PREHEATING

Preliminary tests and those on internal pressure and plasticity were almost entirely on coal heated in the die during compaction. It was realized that different conditions would probably exist if the coal were preheated before compression. Eight tests were accordingly run on preheated Washington County coal, using 42 grams of coal in a 1½-inch spherical die and one on 2.5 grams of coal in a ½-inch spherical die. Six of the tests with the larger

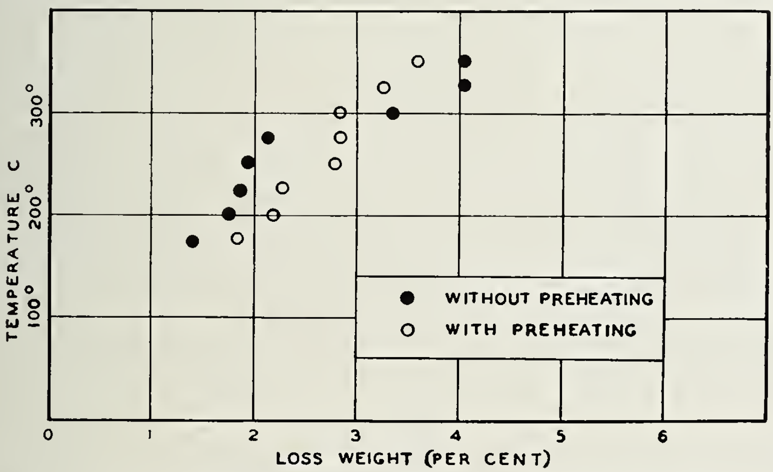

Fig. 5.—Graph showing loss of weight of coal in briquets made with and without preheating.

die were made at 300° C. and a pressure of 15,000 pounds per square inch over a period of 30 minutes, after the coal had been heated in two instances each at 15, 30, and 60 minutes respectively. No briquets resulted. In one instance, using the larger die, the coal was preheated to 225° C. for 15 minutes, and a pressure of 30,000 pounds applied for 3 minutes. The result was a poor briquet. A very poor briquet was formed under similar conditions except that the pressure applied was 25,000 pounds per square inch. The single test on coal in the ½-inch die after the coal was preheated 200° C. for 30 minutes and 30,000 pound pressure applied for 15 minutes resulted in a poor briquet. This briquet was shape B (Fig. 10).

Inspection showed that the eight briquets made from preheated coal were inelastic, dull, dirty to the hands, and mechanically weak as contrasted with those formed without preheating. The weakness of the briquets might be due to oxidation, loss of volatile matter, or loss of moisture. A test made on the Washington County coal heated 15 minutes to 325° C. in a reducing atmosphere and compressed under 20,000 pounds for 15 minutes gave no better briquet than coal not so treated, thereby minimizing but not entirely eliminating the possibility that the weakness of the briquet formed from preheated coal was due to oxidation.

A further series of tests was therefore carried on to determine whether loss in constituents was the cause of the especially poor quality of the preheated coal. It was found that preheating may or may not result in greater loss in weight during briquetting. Twenty-eight samples of Washington County No. 6 coal were dried in an oven one hour at 110°. Half were then preheated to various temperatures varying from 175° to 350° and compaction took place at eight temperature stages, at intervals of 25° C. from 175° to 350° C. One or more compression tests were made on each of the two varieties of coal at each stage. For each five pairs of experiments below 300° C. (Fig. 5) the relative loss in weight was greatest for the preheated coal, whereas the unpreheated coal lost most relative weight at and above 300° C., but at these temperatures only 10,000 pounds pressure or less was applied. For both varieties of coal the loss in weight increased with rise of temperature, being more than 4 per cent for the non-preheated coal for the highest temperature (350° C.) at which these tests were run. Nine briquets were formed but it is noteworthy that in only one case were briquets formed at a temperature below 300° but that above 300° briquets of medium or poor rank were always formed and there was no consistent difference between preheated and unpreheated coals.

The conclusion to be drawn from these tests is that preheating, whether or not loss of weight occurs, is not detrimental provided the temperature of preheating is above 300° C., at which temperature pressure in excess of 3000 pounds per square inch is not necessary for the formation of briquets. Such briquets as were formed, however, were no better than medium quality.

INFLUENCE OF TIME OF COMPRESSION ON CHARACTER OF THE BRIQUETS

The previous tests described, although carried on at various pressure periods, gave no definite basis for an opinion in regard to the part played by time in compaction by compression. A series of 48 systematic tests on Washington County coal was therefore run to determine in what short pressure period the best results might be obtained. These tests were conducted under a variety of temperature conditions, varying from 200° to 325° C. (Table 2), using 42 grams of coal in a 1½-inch spherical die, except in one instance in which 37 grams of coal was used.

TABLE 2—*Effect of varying time at different conditions of temperature and pressure on Washington County No. 6 coal*

(42 grams of coal in a 1½-inch spherical die)

Temperature °C	Pressure pounds	Time periods in minutes	Results
200	30,000	3, 5, 10, 15, 30 and 60.....	
225	30,000	3, 5, 10, 15, 30 and 60.....	Good at 60, 30 and 10 minutes (a).
225	25,000	3, 5, 10, 15, 30 and 60.....	Good at 30 and 15 minutes.
300	25,000	60.....................	
250	25,000	3, 5, 10, 15, 30 and 60.....	
250	20,000	3, 5, 10, 15, 30 and 60.....	
275	20,000	3, 5, 10, 15, 30 and 60.....	Good at 3 minutes.
325	20,000	13 and 30...............	Good at 30 minutes. (b)
300	20,000	3, 5, 10, 15, 30 and 60.....	Good at 3 and 5 minutes (a).
300	15,000	3, 5, 10, 15, 30 and 60.....	Good at 15 minutes.
325	15,000	30.....................	
325	5,000	30.....................	

(a) Best briquets.
(b) A 37-gram sample.

The first good briquets were produced by compression in this series of tests. It will be noted that they were formed at almost every period of time used, but inspection of the briquets showed that the brightest, smoothest, and most solid briquets were obtained by application of pressure of 20,000 to 30,000 pounds per square inch for from 5 to 10 minutes. Only four such briquets were formed. Three were formed at temperatures of 275° to 300° C. at the lower pressure used and one at 225° at the higher.

EFFECT OF SIZE OF COAL ON QUALITY OF BRIQUET

The tests already described were all made on coal crushed to smaller than 4-mesh and contained all sizes of fragments below about ¼ inch. It seemed desirable to know whether more careful sizing at various stages below 4-mesh would produce beneficial results. A screen analysis was made of a face sample of Washington County No. 6 coal that had been crushed to pass through a 4-mesh screen as follows:

Mesh	*Per cent*
—4 + 8	42.8
—8 + 16	26.0
—16 + 28	14.3
—28 + 48	8.7
—48 + 100	4.0
—100 + 200	2.4
—200	1.8

Tests were made on each size of coal using 2.5 gram samples in a ½-inch spherical die. Sixty thousand pounds pressure was applied in each case for 5 minutes at room temperature without preheating. The result was a bri-

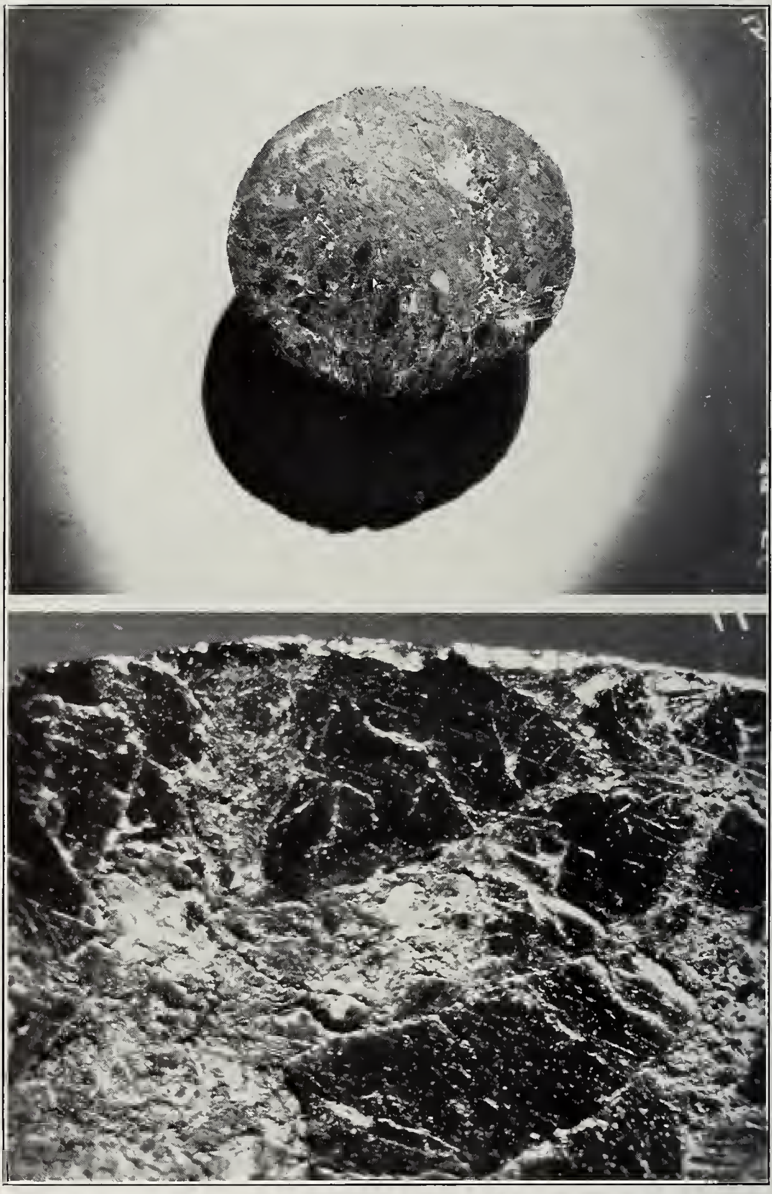

FIG. 6.—Horizontal cross-section of a spherical briquet, natural size (above), and magnified seven diameters (below). Briquet formed by compression of 25,000 pounds per square inch for three minutes at 250° C.

quet in each case except for the —200 mesh coal. Medium quality briquets were formed from coals of —16 + 28, —28 + 48, and —40 + 100 mesh, and poor briquets from the three remaining samples. Briquets made in other series of tests from the whole coal were stronger than those produced from any of the individual sizes, but no strictly comparable tests were made with whole coal under exactly the same conditions. It is believed, however, that a variation in size is desirable, since the small particles fill in the spaces between the larger grains enhancing the tendency to compact when pressure is applied.

INCIDENTAL EFFECTS OF COMPRESSION

Effect of escape of fluid material.—At temperatures above 350° C. excessive melting occurred and difficulty was experienced in confining the liquid products to the die, particularly as the pressure increased. The coal left after such extrusion had taken place, if in the shape of briquets, showed little coherence and was very dirty to the hands. Whatever binding property was possessed by the extruded liquids had obviously been lost.

Case hardening effect.—One of the noteworthy phenomena accompanying the formation of briquets by compression was the development of case hardening effect and a central cavity. In most instances horizontal and vertical cross-sections show a void in the center of the briquet with an outer hard shell extending inward as much as .4 inch. The cause of the development of these characteristics is not understood. These features are quite apparent on visual examination.

Effect of pressure on internal heat.—The application of sudden pressure to coal that had been preheated at 300° C. always resulted in a rise of internal temperature. For the 6 tests measured, the rise amounted to 35° C. but as the thermocouple recorded the temperature of the die, the rise in temperature of the coal must have been considerably greater in view of its relatively small size as compared to that of the die.

Expansion of Briquets.—Measurements show that an expansion of from 5 to 10 per cent takes place after the pressure is removed from the briquets. This indicates that the briquets tend to swell which causes cracking of spherical briquets along the equatorial plane. This condition is common to all spherical briquets made by compression.

Cross-sectional photomicrographs of compressed briquets.—Figure 6 (below) shows a photomicrograph, with seven diameters magnification, of the compression briquet shown in natural size above. The photographs show that the larger particles of coal retain their original shape, and that the space between the particles is filled with plastic, closely packed material resulting

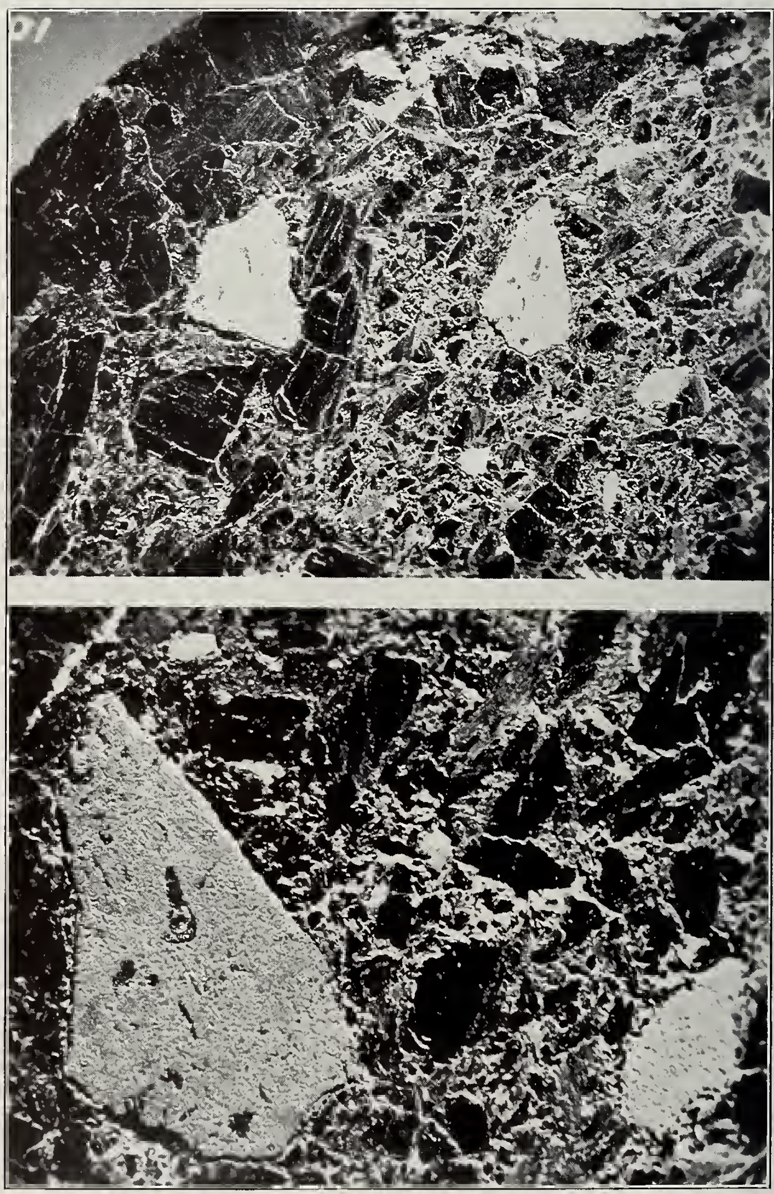

FIG. 7.—Photomicrographs showing cross-section of a briquet magnified 7 diameters (above) and 15 diameters (below). Briquet formed by compression of 25,000 pounds per square inch for thirty minutes at 250° C.

in a coherent briquet. Figure 7 (above) is a photomicrograph, with seven diameters magnification, of a briquet compressed at 25,000 pounds per square inch at 250° C. for 30 minutes. Below is a view of the same cross-section with 15 diameters magnification. This purposely includes a large pyrite particle at the left in order to show the firm compaction around the larger particles in the briquet. The photographs do not definitely indicate that a definite plastic condition resulted from the compression, but very close adherence of the different particles composing the briquet is evident. As the work proceeds, examination of the structure of the briquets using thin sections may reveal more definitely the nature of the bonding phenomenon.

Conclusions

(1) Compression tests indicated that fairly good spherical briquets can be formed by compression using preheated or unpreheated coal at a temperature of about 300° C.

(2) Pressures necessary seem to be about 15,000 pounds per square inch.

(3) No good briquets were made at 15,000 pounds of pressure per square inch if the pressure was applied for less than 15 minutes. This element of time apparently necessary for the formation of briquets by compression is the most serious obstacle to the commercial application of the compression process to briquetting without a binder.

(4) At a pressure of 20,000 pounds per square inch some good briquets were formed in 3 minutes. This time was, however, not always sufficient.

(5) Great care had to be exercised to prevent the extrusion of liquids. No good briquets were formed if liquids were lost.

(6) Great care was necessary to prevent explosive release of pressure on the compressed coal. Such release usually resulted in a disruption of a briquet if one had formed.

(7) In general, these tests indicate that the formation of satisfactory briquets by compression, although apparently possible, would probably require considerable more investigation of the determining factors than conditions seemed to justify, unless experimentation with impaction proved fruitless. For this reason, and because of the serious obstacle represented by the time factor in compression, attention was turned to the impaction method with the realization that further investigation may eventually find a satisfactory method of compaction by compression. The field is by no means fully explored.

CHAPTER III—BRIQUETTING ILLINOIS COAL BY IMPACT

The investigation of the impact process of compacting coal was pursued to somewhat greater length than the compression process because preliminary tests of the impaction process were more encouraging.

Previous Trial of Impact Method

Description of only one process for compacting bituminous coal by impact has been found in the literature, that of the Grondal-Kjellin Briquetting Process in Cardiff, Wales *(81)*. This process, installed at the Tharsis Sulphur and Copper Company, Cardiff, consisted of an impaction of moist, fine coal at room temperature into briquets 6 by 6 by 3 inches for subsequent carbonization or sintering at a temperature of 1500°. So far as known no previous laboratory study has been made of the possibility of producing a finished fuel by impact.

Methods and Equipment of Present Impact Tests

IMPACT MACHINE

A Turner impact machine (Fig. 8), the parts for which were constructed by the Mechanical Engineering Department of Purdue University, was used in the impaction experiments. It consists of two vertical standards serving as guides for drop hammers of various weights, from 50 to 500 pounds, which are raised to the desired height by an electromagnet and dropped by breaking the electric circuit.

BRIQUETTING DIES

The same dies were used in this investigation of briquetting by impaction as had been used previously in briquetting by compression, except that it was found necessary to caseharden the plungers and inner sleeve. These dies were used to impact briquets from 2 to 250 grams in weight, with ½ to 2½ inches diameter. A variety of shapes was used as shown in figures 9 and 10.

METHODS OF HEATING COAL

The preparation of the coal for briquetting by impaction was the same as that for briquetting by compression. The coal was heated by either of

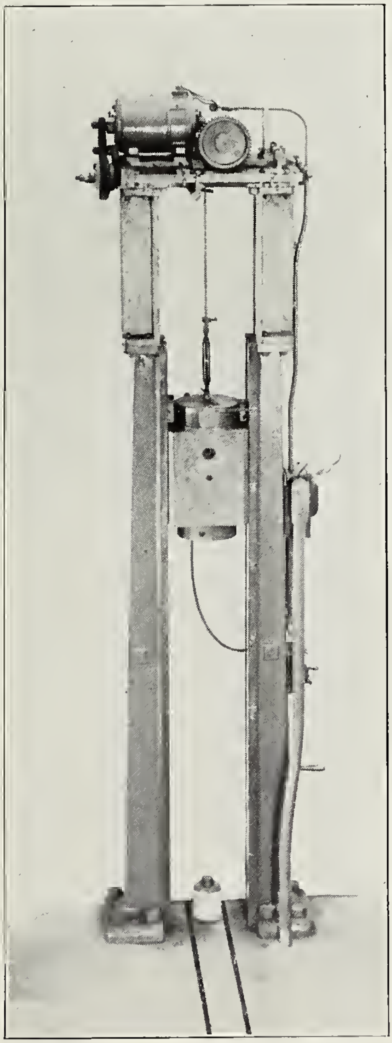

FIG. 8.—Machine for forming briquets by impaction.

two methods. In the first, the coal was preheated in the compaction die held at a given temperature for a specified length of time; in the second, it was preheated for a specified time at a given temperature in an external oven and then transferred to the compaction die heated to the same temperature. In the former method the coal was not stirred so that the temperature dis-

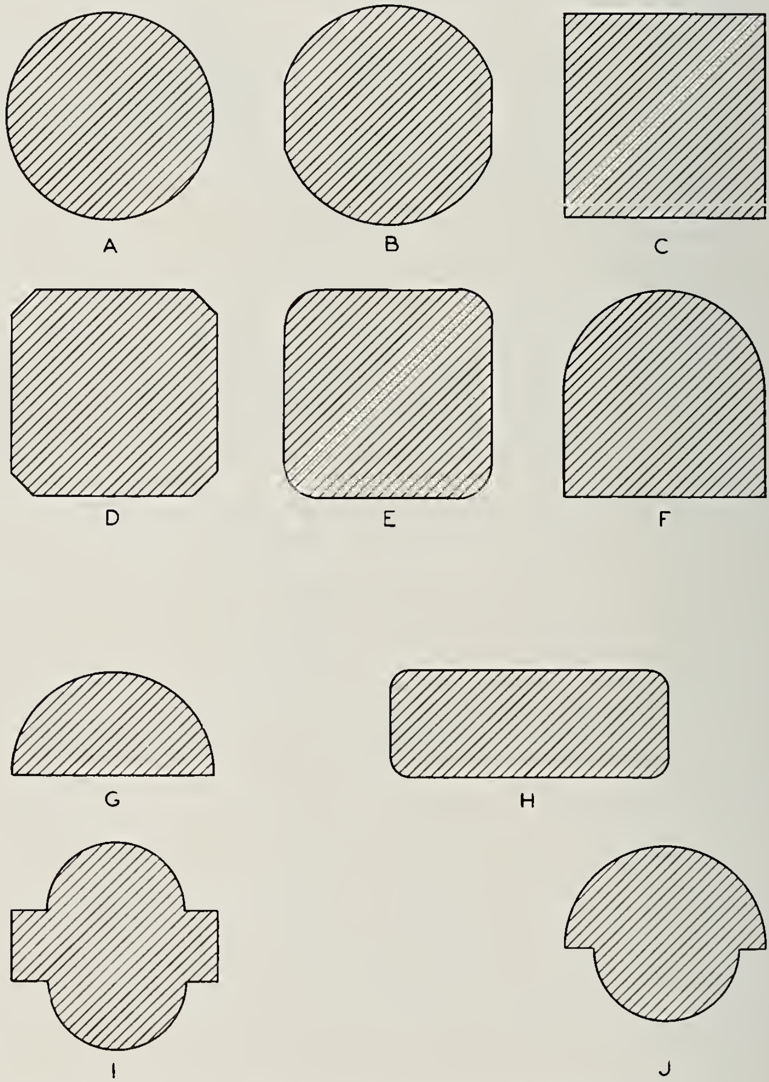

FIG. 9.—Vertical cross-sections of the various shapes of briquets.

tribution within the coal depended upon the thermal conductivity of the coal. The external oven, having a capacity of 400 cc., was constructed for preheating the coal externally to the die. The inner container, around which the heating coil is wound, is separated from the outer by sil-o-cel and alundum cement. The maximum attainable temperature is 600° C., although only temperatures up to 300° C. were used.

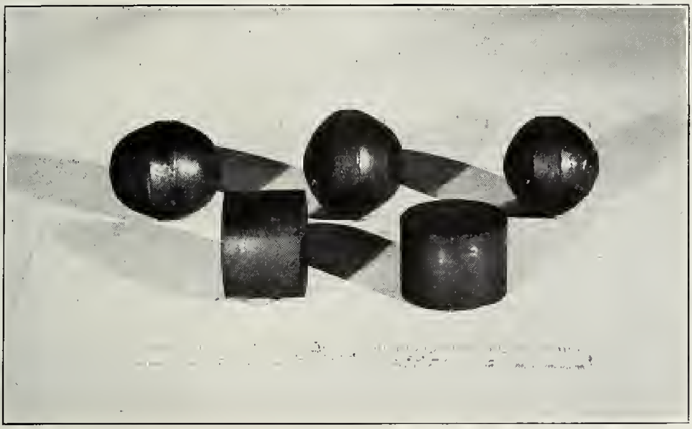

FIG. 10.—Photographs of briquets of shape "B" (above) and "C" (below). One-third natural size.

RANGE OF VARIATION IN CONDITIONS

In the work on impaction the entire range of available impact (50-, 100-, 250-, and 500-pound weights dropped distances from 3 inches to 6 feet) was investigated for temperatures from 25° to 425° C., the coal being preheated various lengths of time up to 60 minutes either in the die or in an external oven. The moisture content ranged from 0 to approximately 20 per cent prior to the time of heating.

ABRASION AND FRIABILITY TESTS

In order to make comparative tests on the mechanical strength of briquets impacted under various conditions and from various coals, two types of tests were used, (a) tumbling and (b) shattering by dropping.

A tumbling barrel was constructed from an 8-inch internal diameter pipe with ¼-inch wall. Three equally spaced 1-inch angle irons that run the length of the barrel acted as baffles. One round steel plate, ¼-inch thick, was fastened on each end by bolts, one of these plates being removable for the insertion and removal of briquets. The barrel was half filled with flint pebbles, with a total weight of 5000 grams and an approximate weight of 25 grams each.

A separate tumbling test was made for each briquet in the barrel rotated at 40 r.p.m. for two minutes, this time having been used in a previous investigation (*48,* Wright). The briquet was weighed before and after tumbling in order to ascertain the loss in weight by abrasion.

Figure 11 is a graph showing cumulative percentage loss of weight by tumbling of a 45-gram briquet impacted from Washington County coal at various periods during a six-hour test. The smoothness of the curve indicates true abrasion with absence of shattering.

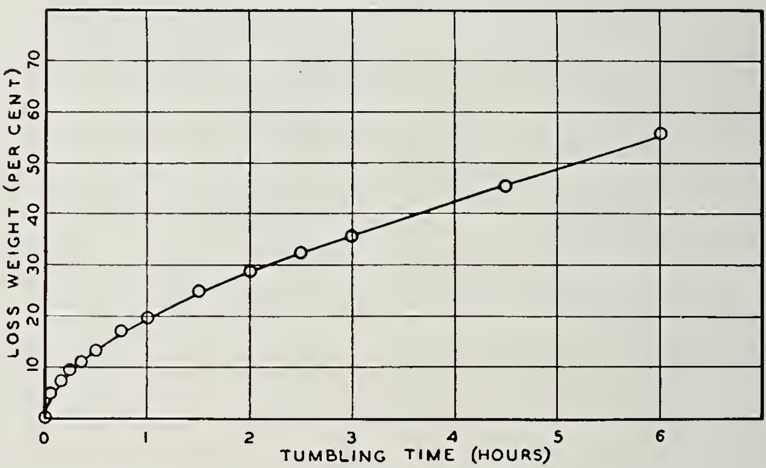

Fig. 11.—Graph showing results of a tumbling test on a briquet formed by impaction as measured by percentage loss of weight.

Individual comparative friability tests (shattering) were also made on each briquet by dropping it upon a one-inch steel plate. Two types of shattering tests were made; in one, the number of times the briquet could be dropped from a height of 3 feet without breakage was determined; and in the other the height was increased one foot after each fall above 3 feet until breakage occurred and the final height without breakage was determined.

Both abrasion and friability tests were arbitrarily selected and represent devices for comparing the relative strength of the briquets and, in some instances, the original coals. The results of the test have no absolute significance other than that which might be suggested by the general character of the conditions imposed. No definite evaluation of the abrasion or friability tests, as such, seemed necessary to determine the relative hardness and toughness of the briquets formed under different conditions by the method of impact. A few tests made on coal, however, provide a rough method of evaluation indicating the relative strength of the briquets as compared with that of coal. The briquets made by compression were not subjected to these tests mainly because too few good briquets were formed to justify systematic testing.

APPLICATION OF INFORMATION GAINED BY COMPRESSION TO IMPACT INVESTIGATIONS

The studies of compression indicated the significance of temperatures around 300° C. in briquetting without a binder. They gave some idea also in regard to the amount of continuous pressure necessary at these temperatures. However, it is impossible to translate values representing continuous pressure into values representing impact since there is no known numerical equivalence between pressure measured in pounds per square inch and that measured in terms of momentum. Newton's second law of motion states that the impact (change of momentum) is proportional to the time during which it acts. Thus impact is the product of a pressure (force) and the time of action. Since it is not feasible to measure this time experimentally it becomes impossible to convert impact into pressure. Therefore, the conditions for briquetting by compaction cannot be applied in briquetting by impaction, it being necessary to determine anew by experimentation the proper value of each physical variable.

Tests of the Impact Process at Room Temperature

These tests consisted: (1) of 8 initial tests with 40 and 50 grams of Washington County coal containing 4 per cent moisture using 500- and 250-pound weights dropped 2, 2½, 5 and 6 feet, with 1, 2, and 3 impacts; (2) of 10 tests to determine possible effect of coal of different sizes obtained by screening crushed coal; (3) of 39 tests to determine the effect of variations in the weight of the hammer and height of the drop; (4) of 29 tests to determine the effect of multiple impact; (5) of 51 tests to determine the effect of variations on the moisture content of the coal; and (6) finally of 11 tests on mixtures of fines and dust. These 148 tests yielded 62 briquets, all of which were poor and indicated the difficulty if not the impossibility of forming briquets at room temperature by the impact method. The different tests and their results are described briefly in the following paragraphs.

(1) INITIAL TESTS

In exploratory experiments an attempt was made to impact Washington County coal containing 4 per cent moisture into 40- and 50-gram spherical briquets at room temperature by dropping a 500-pound hammer 2½ feet and 5 feet; and a 250-pound hammer 2 feet, 5 feet, and 6 feet. At the distance of 6 feet a double and triple impact was also tried. Only three of these eight tests resulted in a briquet, each of which proved mechanically weak as indicated by breaking when dropped on a steel plate from the height of 3 feet. In general the results of this test were negative.

(2) TESTS ON SCREENED FRACTIONS OF CRUSHED COAL

A series of tests was made on the successive screened fractions of a crushed sample of Washington County coal in an attempt to ascertain the influence of such separation of the coal on the strength of the briquet. A 500-pound hammer was dropped 5 feet in an attempt to form a 100-gram briquet of cylindrical shape with rounded edges. From sizes larger than 48-mesh, either no briquet was formed or a weak briquet. From sizes less than 48-mesh no briquets were formed.

It is realized that this is not strictly a test of sizes, because by the method of screen analysis used certain ingredients of the coal, particularly the ash and fusain, tend to concentrate in the smaller sizes. This may be the reason why the smaller sizes yielded no briquets.

(3) EFFECT OF VARIATIONS IN WEIGHT OF HAMMER AND HEIGHT OF DROP

Thirty-nine exploratory single-impact tests were made on Washington County coal containing 4 per cent moisture in an attempt to find the best combination of weight of hammer and height of drop to form a briquet. The weight of the coal varied from 2½ to 150 grams (2½, 20, 25, 40, 50, 60, 66, 75, 80, 100, and 150 grams). The dies were ½, 1, 1½, 2, and 2½ inches in diameter and were in 4 different shapes (B) spherical, (C) cylindrical, (E) cylindrical with round edges, and (H) tabular cylindrical); the weights were 50, 100, 250, and 500 pounds and the height of drop varied from 3 inches to 5 feet. Twenty-eight briquets were formed representing all weights of coal, all sizes of die, all shapes of die (with failures for all shapes except "B" spherical), all weights, and all heights of drop. However, each briquet proved weak when tested by dropping and the method was regarded as unsatisfactory, particularly as the weights and heights used had fairly thoroughly extended through the available range of exploration permitted by the equipment used.

(4) EFFECT OF MULTIPLE IMPACT

A series of 29 tests was next made on Washington County coal containing 4 per cent moisture with multiple impact. Twenty-five grams of coal was used in a cylindrical die (type "C") 1-inch in diameter. Six tests were made with a 50-pound weight dropped 1, 2, 4, or 6 feet, the impacts numbering 2, 3, 4, or 6. Six poor briquets resulted but the best was made with a triple impact and 6-foot drop. Six tests were made with a 100-pound weight dropped, 1, 1½, 2, 3, or 5 feet, with the same variety of impacts as before. Except for the 1-foot drop with 4 impacts briquets were obtained in all cases, but all were poor. Seven tests were made with the 250-pound weight with drop at 4, 6, or 10 inches and 1, 3, or 5 feet and with 2, 3, or 4 impacts. Briquets were formed in each case, but all were poor. For the 500-pound weight the drop consisted of 2 inches, 3 inches, or 5 feet, with 2 or 3 impacts. The ten impacts produced 7 poor briquets, both failures and success being obtained with the 5-foot drop, using both 2 and 3 impacts. It is significant that although only poor briquets were made, multiple impacts actually failed to produce briquets in only 4 tests. The fact, however, that all briquets were poor resulted in the abandonment of this line of investigation for the time being. The evident advantage of the double impact was remembered, however, in connection with tests at elevated temperatures.

(5) EFFECT OF VARIOUS PERCENTAGES OF MOISTURE

Using the Franklin County No. 6 coal, 51 tests were made to determine the effect on the formation of briquets of various percentages of moisture in the coal. Starting with "dry" coal the moisture content was increased successively to 1.5, 3.0, 3.5, 4.3, 5.4, 6.3, 6.9, 7.2, 8.0, 9.5, 9.7, 12.0, 14.0, 15.0, 15.7, and 17.5 per cent. Dies of 1, 2, and 1½-inch diameter of cylindrical shape in three varieties ("C", "E", and "H", Fig. 9) were used. The weight of 500 pounds was dropped five feet in most cases although in one case each it was dropped only 2 inches, 3 inches, 9 inches, 1 foot and 1½ feet. In two cases it was dropped 6 inches and in 4 cases 2 feet. In five instances there were two drops each of different distances, 1 and 5; 1 and 5; 3 and 5; 4 and 5; 1 and 5 feet, respectively. Seventeen poor briquets resulted. Two at 4.3 per cent moisture, three at 5.4 per cent, one at 6.9 per cent, two at 8 per cent, three at 9.7, three at 15 per cent, one at 15.7 per cent and two at 17.5. More briquets were made from coal with 8 per cent or more of moisture than from the drier samples of coal but these crumbled upon exposure indicating the probability that the compaction was largely due to moisture and was of a temporary character. It seemed probable, therefore, that moisture content was not a determining factor in forming satisfactory briquets from non-preheated coal.

CONCLUSIONS

Exploration of the possibility of forming good briquets from non-preheated coal under various conditions of impact by varying the weights used up to 500 pounds (the capacity of the machine used), the number of impacts up to 6, the height of the drop up to 6 feet (likewise the capacity of the machine), the moisture content of the coal, and the size and shape of the briquet, resulted entirely in negative results. It seemed improbable with the equipment available that any combination of impact and size or shape of die would yield a satisfactory briquet. This line of experimentation was therefore dropped.

Tests of the Impact Method at Elevated Temperatures

Tests of the impact method at raised temperatures started with double impact because two impacts were found to have produced the best results upon unheated coal. Tests by double impact were made first on coal preheated in the die and then upon coal preheated in an oven. Investigations were made of the effect of variations in moisture content and of the shapes of briquets. Multiple impact was briefly investigated and rejected. Successful briquets were produced by the double-impact method, but the obvious advantage of single impact called for investigation of this method on coal heated both in the die and the oven. It being found possible to produce satisfactory briquets by single impact upon coal preheated in an oven, the best conditions for the formation of briquets were determined and a series of confirmatory tests was run on a group of representative coals. The general procedure and results of this part of the investigation are described below.

Tests Made With Double Impact

(1) Effect of Preheating the Coal in the Die

Using Washington County coal containing 4 per cent moisture, 62 tests were made to determine the effect of preheating the coal in the die to temperatures ranging from 100° to 350° C. Hammers 250 and 500 pounds in weight were dropped twice from various heights but mainly from 6 inches and 5 feet, and from 5 feet and 6 feet. Other heights used were 1 foot and 5 feet, 2½ feet and 5 feet, and 6 inches and 6 feet. The amount of coal used was variously 45, 75, 100, 125, and 200 grams and the shape of the dies was both spherical and cylindrical ("A", "B", "C", "D", "E", and "H", Fig. 9). The time of preheating varied from 10 to 60 minutes but about half the tests (32) were made with coal heated only 10 minutes.

The results of this test were 47 briquets of which 14 were good and 11 of medium quality. The best briquets were formed with 45 grams of coal heated for 10 minutes in the die at 300° C. and impacted with a 250-pound hammer dropped twice from the height of six feet upon a cylindrical die (type "C", Fig. 9) 1½ inches in diameter. In no case under these definite conditions did a good briquet fail to form.

(2) The Effect of Preheating the Coal in an Oven

Since there would be an obvious advantage in commercial operation in preheating the coal in an oven rather than in the die, tests were made with coal so treated. The conditions were more restricted than in the previous test because of the results obtained upon coal preheated in the die. Twenty-nine tests were made on Washington County No. 6 coal, 5 tests on Sangamon

County No. 5 coal and 6 tests on Jackson County No. 6 coal. Forty-five grams of coal and a cylindrical die, type "C", was used in each case. A weight of 250 pounds was in each case dropped twice a distance of 6 feet upon coal that had been heated to 300° C. in most cases, but to only 200° C. in some cases. The time of preheating varied from 3 to 60 minutes but in most cases did not extend beyond 15 minutes. Forty briquets were formed of which only 4 were graded as good and 18 of medium grade. The proportion of good briquets was so small as to condemn this procedure.

(3) EFFECT OF MOISTURE IN COAL PREHEATED IN THE DIE

In view of the successful compaction by repeated impact upon coal heated in the die investigation was made of the possible effect upon the briquets of variations in moisture content. Washington County and Franklin County No. 6 coal and Will County No. 2 coal were used with moisture contents varying from 3 to 15 per cent. Fifty-two tests were run under a variety of conditions, mainly with a spherical die using a 500-pound weight but in a few tests a 250-pound weight was used. These tests combined investigation of variations in moisture content and experiments with multiple impact and in no instances were all the best conditions as regards size of sample and shape of die, weight of hammer and temperature and time of heating entirely met. Consequently although 20 briquets were formed, none was good. Since most of these briquets were formed from coal with moisture content less than 10 per cent the conclusion was drawn that the reduction in moisture due to preheating probably has no detrimental effect.

(4) EFFECT OF SHAPE OF DIE ON QUALITY OF BRIQUETS FROM PREHEATED COAL

During these investigations dies of various forms were used (Fig. 9). As the tests began to result in the formation of briquets of satisfactory character it was found that some difference in quality was obtained from different dies. At this stage, therefore, in order that the subsequent tests might be concentrated on the dies that would give the best results a series of 29 tests was run on Washington County coal using 1½-inch dies of the 10 different shapes shown in figure 9. The amount of coal used varied from 20 to 50 grams but other conditions were uniform, with three exceptions. A 250-pound weight was dropped twice a distance of six feet upon coal preheated in the die 10 minutes at 300° C. Shapes "C", "F", and "G" produced 7 good briquets, "F" most frequently (4 times). However, the two briquets produced in the right angle cylinder form "C" were distinctly superior to those produced in the form of the cylinder with the rounded ends ("F"). A compilation of all tests that had been made by impaction under the best conditions, including the 29 of this series, show the superior advantage of the "C" type of die.

TABLE 3—*Results obtained with dies of different shape by all tests under most favorable conditions (a) made previous to final series on uniformity of coals (Table 9)*

Shape	Good	Medium	Poor	Negative
A	....	....	....	3
B	....	2	3	3
C	31	....	....	....
D	....	....	3	....
E	....	3	2	....
F	4	2	1	1
G	1	1	....	....
H	....	....	1	3
I	....	1	....	....
J	....	....	....	2

(a) 45 grams of coal, 250-pound weight, 2 drops of 6 feet each, coal preheated 10 minutes in die at 300° C; or 45 grams of coal, 500-pound weight, 1 drop of 4½ feet, coal preheated 10 minues in oven at 300° C.

The right angle cylinder with height slightly less than diameter was accordingly selected as the most favorable shape. In such a shape, contrasted to spherical, a minimum of internal stresses is developed as evidenced by absence of cracking. In the case of all spherical briquets or cylindrical briquets with spherical ends ("F") there is a troublesome tendency of the hollowed plunger to "bell" upon impact making withdrawal difficult.

(5) EFFECT OF MULTIPLE IMPACT UPON QUALITY OF BRIQUETS FROM COAL PREHEATED IN DIE

The series of tests on the effect of a varying moisture content of the coals on the character of the briquets formed by impact (see paragraph 3 above) obtained some briquets from three impacts. These tests indicated that the most favorable combination for coal preheated in a die was obtained by using a 250-pound weight and dropping it 6 inches, 5 feet, and 5 feet in a triple impact. Accordingly a series of 16 tests using this combination was run, using spherical and cylindrical dies, and preheating the coal either at 200° or 250° C. for 10 minutes or 300° C. for 10 or 20 minutes. The dies varied from 1½ to 2½ inches in diameter and the weight of the coal from 42 to 200 grams. Washington County coal was used. Seven briquets were formed only three of which were good, viz.—two spherical ("B") and one cylindrical ("C") briquet each 1½ inches in diameter and each made from 55 to 60 grams of coal preheated 10 minutes at 300° C. A single test was made using a cylindrical die ("C") to determine the effect of 10 successive impacts of the 250-pound hammer dropped from 6 feet on 45 grams of coal preheated in the die 10 minutes at 300° C. No briquet was formed. Inspection showed that the individual grains of coal had been powdered by repeated impact.

The general conclusion to be drawn from these studies of repeated impact is that although double impact of a 250-pound hammer from 6 feet produced good briquets, multiple impacts beyond 2 added nothing to the quality of the briquets formed and might result in the entire failure of their formation. Furthermore in view of the fact that it had been found possible to make better briquets by two impacts than by compression, investigation was certainly desirable of the possibility of producing satisfactory briquets by a single impact.

Tests with Single Impact

The tests with a single impact consisted first of a series of tests with coal preheated in the die, which gave good results. This was then followed by a series of tests with coal preheated in an oven under the definitely favorable condition determined by the previous test for coal preheated in the die. These tests also produced satisfactory results. The details of these tests are described in the following paragraphs.

(1) TESTS OF SINGLE IMPACT ON COAL PREHEATED IN THE DIE

Forty tests were made on Washington County coal using 45 to 250 grams in dies of various forms and sizes from 1½ to 2½ inches in diameter. A 500-pound weight was dropped once 3 inches, 6 inches, 1, 2, 3, 4, 4½ or 5 feet upon coal preheated in a die 10 to 20 minutes at 100°, 150°, 200°, 300°, 350°, 400°, or 425° C. Twenty-one briquets were formed but the 7 good briquets were formed from 45 grams of coal in the cylindrical die, with coal heated at 300° for 10 minutes, the drop, however, varying from 3 to 5 feet. Apparently the best of these were formed with a drop of 4½ feet. Moreover, with this type of impact, good briquets were always formed.

(2) TESTS OF SINGLE IMPACT ON COAL PREHEATED IN AN OVEN

Two tests were then made on the Washington County coal, preheated in an oven and using the most favorable conditions, namely, 45 grams of coal and a cylindrical die 1½ inches in diameter, a 500-pound weight, and coal preheated in an oven for 10 minutes at 300°. Both tests yielded satisfactory results.

Character of the Briquets Formed by Impact

The purpose of this investigation is accomplished in defining the laboratory conditions under which good briquets may be formed from Illinois coal without an artificial binder. It is desirable, however, to indicate more definitely the character of the product. This can be done partly by description and photographs and partly by recording the results of certain arbitrary tests. Finally it is desirable to know with what success the proposed methods for forming good briquets can be applied to a variety of Illinois coals (see Chapter IV).

Fig. 12.—Cylindrical briquets formed by impaction, shown half size. The rounded edges are due to abrasion during tumbling tests.

DESCRIPTION

The cylindrical briquets which have been successfully formed from Illinois coal are about 1½ inch in diameter and 1 inch in height (Fig. 12) and weigh about 45 grams. They are, therefore, about the size of No. 3 nut coal, one of the most acceptable sizes for the efficient combustion of Illinois coal in the domestic furnace. The briquets are dull in appearance but have a smooth very even surface. They are entirely dustless and do not rub off on the hands in handling.

The appearance of the good briquets formed by two impacts is the same as the appearance of those formed by one.

The interior structure of the briquets is that of a closely packed aggregate (Figures 13 and 14, above). Magnification of a polished surface of a fragment of a well solidified briquet shows the closeness of the compaction and likewise shows that the compaction has taken place without fracturing of the larger fragments. Although compaction may be in part due to the development of slight plasticity of the finer fragments, the polished surfaces, even when magnified, do not present very convincing evidence that there has been much melting. Probably the phenomena of compaction will have to be studied with the help of thin sections before it will be thoroughly understood.

TESTS OF HARDNESS AND TOUGHNESS

The equipment used in estimating the relative strength of the briquets has been described (pages 33-34). It was only when briquets of at least apparent satisfactory strength were finally produced by the impact method that tests of strength were necessary or even desirable. It is realized that the tests devised do not show absolute strength except as substances of known hardness are subjected to the same tests. A few tests made subsequently with coal give some idea of the actual strength of the briquet and, what is more important, some idea of their relatively greater strength as compared with coal. During the exploratory investigations 35 tumbling tests were made on briquets made by the two-impact method and 15 tests were made on briquets made by the one-impact method. In the case of the two-impact briquets, the 19 designated as good showed a percentage of degradation as follows

Loss in weight	*Number of briquets*
Between 5 and 6 per cent	2
Between 4 and 5 per cent	3
Between 3 and 4 per cent	3
Between 2 and 3 per cent	3
Between 1 and 2 per cent	8

Nine briquets regarded as of medium grade showed degradation under the same conditions from 5.3 to 11.5 per cent, and the 7 "poor" briquets showed degradation of 11.6 to 29 per cent.

In the case of the one-impact briquets, 15 tumbling tests were run. The 12 good briquets showed the following results:

Loss in weight	*Number of briquets*
Between 3 and 4 per cent	2
Between 2 and 3 per cent	1
Between 1 and 2 per cent	9

The three medium grade briquets all showed a loss of weight in excess of 6 per cent. These tests definitely indicate the relative strength of the good briquets formed under the most favorable conditions.

FIG. 13.—Horizontal cross-section of impacted cylindrical briquet, natural size (above), and the same magnified 15 diameters (below).

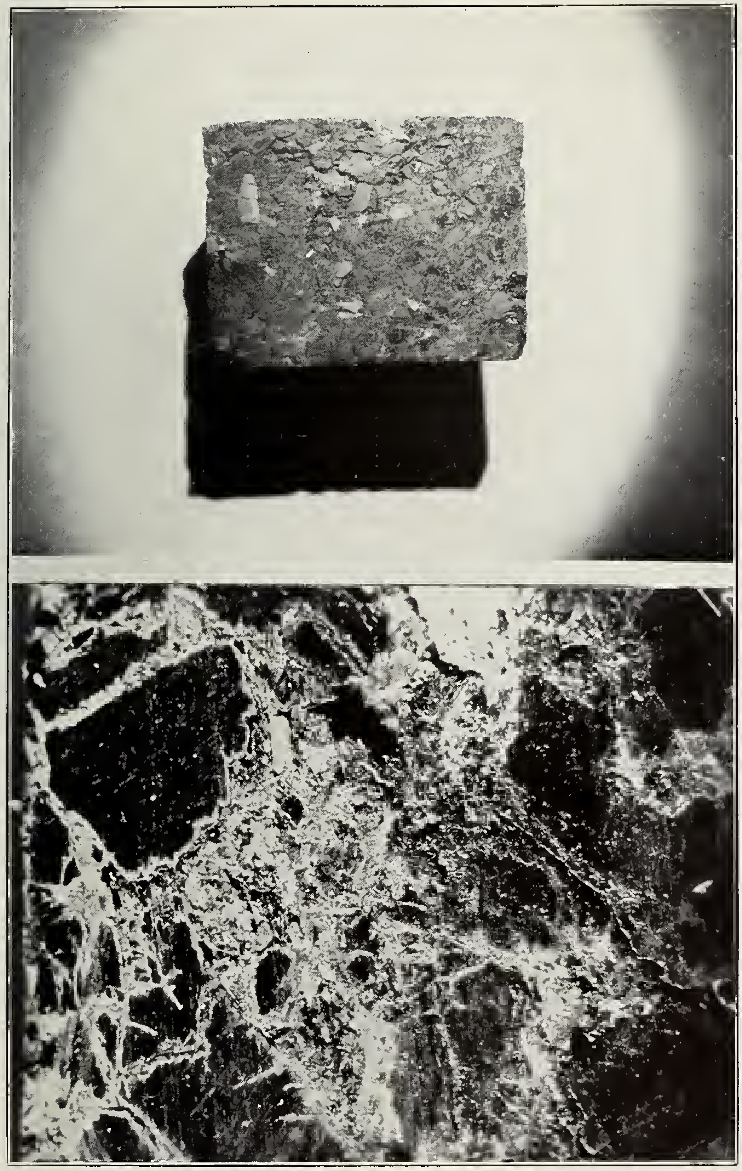

FIG. 14.—Vertical cross-section of impacted cylindrical briquet, natural size (above), and the same magnified 15 diameters (below).

TABLE 5—*Chemical character of Franklin, Washington and Will County coals in various stages of the briquetting process and briquets made from these coals, with the softening temperature of the ash**

(All values except unit coal calorific values on an as received basis. Moisture probably somewhat different from mine moisture)

Location of coal by county	Analysis No.			Moisture			Volatile Matter			Ash			Ash Softens, °C.			Sulfur			B. t. u.			Unit coal (†) B. t. u.		
	Franklin	Washington	Will	Franklin	Washington	Will	Franklin	Washington	Will	Franklin	Washington	Will	Franklin	Washington	Will	Franklin	Washington	Will	Franklin	Washington	Will	Franklin	Washington	Will
Coal as loaded (car or tipple sample) (‡)	C409	C415	C418	8.1	15.1	9.1	34.7	35.6	43.5	6.2	10.7	4.7	2518	2030	1926	1.10	3.09	2.92	12401	10517	12369	14609	14465	14517
Oven heated 10 minutes—200° C.	C410	.....	.....	4.9	.....	.....	36.5	.....	.....	6.4	.....	.....	2518	.....	.....	1.12	.....	.....	12874	.....	.....	14633	.....	.....
Oven heated 10 minutes—300° C.	C411	C416	C419	3.1	2.3	3.0	37.0	40.2	44.6	6.8	12.7	5.2	2525	2044	1918	1.07	3.66	3.20	13003	12130	13116	14533	14575	14463
Briquets 10 minutes—300° C. in oven (preferred conditions).	C413	.....	.....	2.1	.....	.....	35.7	.....	.....	7.3	.....	.....	2493	.....	.....	1.18	.....	.....	13032	.....	.....	14525	.....	.....
Die heated 10 minutes—300° C.	C412	.....	.....	2.5	.....	.....	39.9	.....	.....	6.9	.....	.....	2541	.....	.....	1.06	.....	.....	13042	.....	.....	14523	.....	.....
Briquets 10 minutes—300° C. in die.	C414	C417	C420	1.9	1.2	1.9	36.5	40.1	44.9	6.8	12.4	5.0	2561	2048	1918	1.05	3.54	3.02	13121	12257	13323	14486	14484	14469

(*) Analyses made in Analytical Laboratory, State Geological Survey.
(†) Unit coal is dry, mineral matter free coal.
(‡) Not a standard sample.

TUMBLING TESTS ON ILLINOIS COALS

The results obtained by subjecting selected lumps of Illinois coal to 2 minute tumbling tests similar to those applied to the briquets are given in Table 4.

TABLE 4—*Results obtained in tumbling seven blocks of raw coal cut from natural benches*

Source	*Loss of weight Per cent*
Two minutes	
Franklin County Coal No. 6	1.4
Franklin County Coal No. 6	0.9
Washington County Coal No. 6	2.6
Will County Coal No. 2	6.6 (a)
Franklin County Coal No. 6	4.2
Fulton County Coal No. 1	4.2 (b)

(a) Broken in five pieces.
(b) Broken in four pieces.

The chemical characteristics of the coals and the softening temperature of the ash at various stages in the briquetting process of compaction by one impaet is summarized in Table 5.

The signifieant characteristics are the relatively low moisture contents of the briquets as compared with the coal. It is noteworthy that the moisture content of the briquets is about the same regardless of the original moisture eontent of the coal. This is of course greatly to the advantage of the central and northern Illinois high-moisture coals. Volatile matter on an ash- and moisture-free basis deereases slightly. The amount of ash on the moist basis neeessarily increases in the briquets sinee there is no decrease in the actual amount of ash. The ash softening temperature remains unchanged. The actual sulfur content probably does not change so that the proportion in the briquets is slightly higher. There is no definite indication of any change in the heating value of the coal substance due to briqueting. The differences notieeable are not sufficiently substantiated to warrant regarding them as real. If, as seems to be true, the unit coal values are essentially unchanged by briquetting, this indicates no loss of heat value of oxidation and also indieates that the heat value of the briquet will necessarily be higher than that of the coal because of the low moisture content of the briquet.

It is apparent that one great advantage of the briquet over the raw coal is the reduced moisture eontent and the resulting higher heat value. This will be a great advantage if subsequent tests bear out the results of preliminary trials whieh indicate the relative impermeability to water of the briquets as compared to coal.

Conclusions Drawn from Results of Impact Tests

(1) The double-impact method produced good briquets when 45 grams of coal was impacted by two falls of a 250-pound weight from a height of 6 feet upon coal heated 10 minutes at 300° in a cylindrical die.

(2) The single-impact method produced somewhat better briquets when 45 grams of coal was impacted by the fall of a 500-pound weight from a height of 4½ feet upon coal heated 10 minutes at 300° in a cylindrical die.

(3) Equally good briquets were obtained as under conditions described under (2) if the coal was heated for 10 minutes in an oven instead of a die.

(4) The most practical method of forming briquets is by the use of one impact on coal preheated in an oven. Exploratory tests indicate that the use of 45 grams of coal, preheated 10 minutes at 300° C. and placed in a cylindrical die, if compressed with a sudden impact equivalent to the drop of 500 pounds a distance of 4½ feet, will probably give a high percentage of success.

(5) The tumbling tests indicate at least a fair degree of resistance to fracture.

(6) The briquets are of desirable size and clean to handle.

(7) The chemical quality of the coal is improved by briquetting, due mainly to the loss of water. There is slight increase in ash and sulfur content, which, however, does not affect the temperature of ash softening.

(8) Laboratory tests of representative series of Illinois coals is desirable. These were accordingly made, and are described in the following chapter.

CHAPTER IV.—BRIQUETTING OF REPRESENTATIVE ILLINOIS COALS BY IMPACT

Pursuant to the conclusions reached at the close of the last chapter, the impaction process, with conditions controlled to agree with those under which good briquets had been made during the exploratory series of tests, was next systematically applied to a representative series of Illinois coals.

At the time these tests were started it was not clearly apparent that the method of single impact was superior to the method of double impact. However, tests had shown that any coal that could be briquetted by the double-impact method could be impacted by the single-impact method, and, indeed, that there were fewer failures by the single-impact method than by the double. It is probable, therefore, that successful tests by the double-impact method are equivalent to successful tests by the single-impact method.

Coals Tested

The coals used in the final series of impact tests consisted of fresh 3/8 inch nut coal from 3 mines in Franklin County, one mine in Williamson County, two mines in Perry County, and one in Macoupin County, all working coal No. 6, one mine in Saline County working Harrisburg No. 5 coal, and one mine in northern Illinois working No. 2 coal, and lump coal samples from mines in coal No. 6 in Franklin and Jackson counties, and from a mine in coal No. 5 in Sangamon County. In addition there were also used parts of large face samples of coal collected by the Survey sampling party during 1931 at mines in coal No. 6 in eleven mines in Montgomery, Macoupin, St. Clair, Perry, Washington, Randolph, Franklin, and Williamson counties. These latter samples had been stored in the basement of the Survey offices in covered tin cans. They had probably somewhat deteriorated as compared with strictly fresh coal. The coal taken for use in the impaction tests from these samples, and from two other samples in Franklin and one in Perry County was all cleaned by a 1.3 gravity separation, only the float fraction being used. The amount of coal so used varied from 46 to 74 per cent of the total sample before cleaning.

Tests and Results

In the series of tests, the results of which are given in full in Table 9, some coals were tested with the double-impact method using a 250-pound weight and 2 six-foot drops and others were tested with the single-impact method using a 500-pound weight and a 4½ or 5 foot drop. There was some variation in the weight of the coal used from 35 to 60 grams. In two cases 250 grams of coal was used. Toward the end of the series of tests, however, conditions were kept consistently at the best for single and double impact. Altogether 156 tests were run and 57 successful briquets made, for none of which did the degradation by the tumbling test exceed 5.72 per cent for the 36 tested.

The double impact under the conditions determined as most favorable (45 grams of coal, a 1½-inch cylindrical die, a 250-pound weight dropped 6 feet twice on coal heated 10 minutes in the die) was tried 61 times and produced 27 good briquets, that is briquets with a degradation loss of less than 6 per cent in the tumbling test. Coal from five mines failed to yield good briquets by this method.

The single impact under the strictly prescribed condition (40 grams of coal, 1½-inch cylindrical die, a 500-pound weight dropped 4½ feet on coal preheated to 300° for 10 minutes in the oven) was applied 36 times and produced 28 good briquets, 4 briquets of medium and 3 of poor quality. In the three cases initial failures to produce good briquets from a coal were followed by successful tests. No coal tested by this method failed to yield a good briquet. The best briquets were obtained from the lighter, low ash fraction separated by float-and-sink methods. In the tumbling tests made on these coals none showed a degradation loss in excess of 3.31 per cent. Greater difficulty was experienced in obtaining good briquets by the double-impact method on coals from Franklin, Williamson, and Perry counties than from coals elsewhere in the State, but tests of these coals by the single-impact method gave good briquets.

SHATTERING TESTS OF BRIQUETS MADE BY DOUBLE IMPACT

Shattering tests were made on some of the good briquets formed by the double-impact method in the last series of tests (Table 6). These tests consisted in determining the number of drops on a steel plate from a height of 3 feet necessary to break the briquet. The second test determined the maximum height from which the briquet might be dropped without breaking, the briquet being dropped initially from 3 feet and successively from heights increased 1 foot at a time until the briquet is broken. No similar tests were made upon briquets made by a single impact.

TABLE 6—*Strength of a briquet made from various coals by double impact as determined by dropping tests*

County	Number of drops from 3 feet	Height of drop in feet
Franklin (a)	5	6
Franklin (b)	7	6
Franklin (d)	3	6
Jackson	11	8
Macoupin (a)	9	8
Marion	15	10
Perry (a)	9	6
Perry (b)	8	6
Saline	6	6
Sangamon	14	7
Will	8	6
Williamson (a)	5	4

45-gram briquets made from various coals preheated in die for 10 minutes at 300°C. and formed by double impact of a 250-pound hammer dropped 6 feet.

The maximum height from which a briquet may be dropped without breaking is obtained by dropping the briquet from 3 feet and successively from heights increased 1 foot at a time until briquet is broken.

TABLE 7—*Percentage loss of weight of double- and single-impact briquets during tumbling tests*

County	Percentage Moisture	Percentage loss after 2 minutes tumbling	
		A	B
Franklin (a)	8.7	7.85	3.30
Franklin (b)	8.1	11.00	4.65
Franklin (c)	....	....	4.37*
Franklin (d)	8.7	8.25	7.48
Jackson	8.2	4.60	2.69
Macoupin (a)	12.4	4.02	5.97
Marion	4.0	2.78	1.66
Perry (a)	9.0	6.50	5.72
Perry (b)	8.7	10.20	4.43
Saline	6.6	4.60	1.63
Sangamon	12.5	2.24	1.47
Will	....	7.30	2.15
Williamson (a)	7.7	13.40	5.47

(A) 45-gram briquets made from coal preheated in die for 10 minutes at 300° C. and formed by double impact of 250-pound hammer dropped 6 feet.

(B) 45-gram briquets made from coal preheated in oven for 10 minutes at 300° C. and formed by single impact of 500-pound hammer dropped 4½ feet.

*Preheated 10 minutes at 200° C. in oven.

TABLE 8—*Percentage loss of weight of briquets made from various coals cleaned by 1.3 specific gravity separation*

County	Percentage float	Percentage loss after 2 minutes tumbling
Calhoun	63.68	1.87
Franklin (b)	74.98	3.31
Franklin (d)	65.20	2.72
Macoupin (b)	52.04	2.14
Montgomery	53.28	1.37
Perry (b)	53.32	2.68
Perry (c)	52.73	2.44
Randolph	46.00	1.63
St. Clair	48.75	1.34
Washington	63.35	1.60
Williamson (b)	47.88	2.35

45-gram briquets made from cleaned coal preheated 10 minutes at 300° C. in oven and formed by single impact of a 500-pound hammer dropped 4½ feet.

RELATIVE STRENGTH OF BRIQUETS MADE BY DOUBLE IMPACT AND THOSE BY SINGLE IMPACT

Tumbling tests upon the briquets made by the two demonstrated methods of impact showed the greater strength of the briquets made by the single impact method, the degradation with one exception being consistently less for the single impact briquets than for the double impact briquets.

Conclusions

The general conclusions to be drawn from the impact tests are:

(1) That the double-impact method will commonly produce briquets from Illinois coals but that briquets are less definitely obtained from Franklin-Williamson district coals than from coals elsewhere in the State and that cleaned coal gives better results than the raw coal.

(2) The single-impact method gives larger promise of success for all Illinois coals than the double-impact method, particularly if cleaned coals are used.

(3) The impact method is much to be preferred over the compression method because of the length of time the briquet must remain in the die (15 minutes) and the general weakness of the briquet formed by compression.

TABLE 9—*Systematic tests under favorable conditions of impact on a variety of Illinois coals*

Test number	County and moisture	Amount (grams) (*)	Diameter of die (inches)	Shape of die	Weight of hammer (pounds)	Height of drop (feet)	No. of impacts	Temperature, °C. (†)	Preheating in die (minutes)	Preheating in oven (minutes)	Briquet (‡)	Loss of weight, percent (tumbling). Remarks
	Franklin County (c)—											
618	9.5	40	1.5	C	500	6	1	300	0	10	G	3.04.
619	9.5	40	1.5	C	500	5	1	300	0	10	M	8.18.
620	9.5	40	1.5	C	500	5	1	300	0	20	P	
621	9.5	40	1.5	C	500	5	1	300	0	30	P	
622	9.5	250	2.5	C	500	5	1	300	20	0	—	
623	9.5	250	2.5	C	500	5	1	300	10	0	P	
624	9.5	40	1.5	C	500	5	1	300	0	0	P	
625	9.5	40	1.5	C	500	4.5	1	300	0	10	M	Float on 1.33 9.1
626	9.9	40	1.5	C	500	4.5	1	300	0	10	M	Float on 1.33 7.5
627	9.5	40	1.5	C	500	4	1	300	0	10	M	7.55.
628	9.5	40	1.5	C	500	3	1	300	0	10	P	29.3.
629	9.5	40	1.5	C	500	2	1	300	0	10	P	Broke.
630	9.5	40	1.5	C	500	1	1	300	0	10	—	
631	9.5	40	1.5	C	500	5	1	200	0	30	P	12.4.
632	9.5	40	1.5	C	500	5	1	200	0	20	M	5.45.
633	9.5	40	1.5	C	500	5	1	200	0	10	G	4.37.
634	9.5	45	1.5	C	500	4.5	1	200	0	10	P	
635	9.5	45	1.5	C	250	6	2	300	10	0	—	
636	9.5	45	1.5	C	250	6	2	300	10	0	—	
637	2.4	35	1.5	E	250	6	2	300	10	0	M	
638	2.4	35	1.5	F	250	6	2	300	10	0	M	

639	9.5	60	1.5	C	250	.5; 5; 5	3	300	5	0	—	
640	9.5	60	1.5	C	250	.5; 5; 5	3	300	10	0	—	
641	9.5	60	1.5	C	250	.5; 5; 5	3	300	10	0	P	
642	9.5	60	1.5	C	250	.5; 5; 5	3	300	20	0	P	
	Jackson County—											
643	8.2	45	1.5	C	250	6	2	300	10	0	G	4.1.
644	8.2	45	1.5	C	250	6	2	300	10	0	G	5.1.
645	8.2	45	1.5	C	250	6	2	300	10	0	G	
646	8.2	45	1.5	C	250	6	2	300	10	0	G	
647	8.2	45	1.5	C	250	6	2	300	10	0	G	
648	8.2	35	1.5	F	250	6	2	300	10	0	M	
649	8.2	35	1.5	F	250	6	2	300	10	0	M	
	Sangamon County—											
650	12.5	45	1.5	C	250	6	2	300	10	0	G	2.5.
651	12.5	45	1.5	C	250	6	2	300	10	0	G	2.0.
652	12.5	45	1.5	C	250	6	2	300	10	0	G	
653	12.5	45	1.5	C	250	6	2	300	10	0	G	
654	12.5	45	1.5	C	250	6	2	300	10	0	G	
655	12.5	35	1.5	F	250	6	2	300	10	0	G	
656	12.5	35	1.5	F	250	6	2	300	10	0	G	
	Will County—											
657	2.67	45	1.5	C	250	6	2	300	10	0	G	5.0.
658	2.67	45	1.5	C	250	6	2	300	10	0	M	9.6.
659	2.67	45	1.5	C	250	6	2	300	10	0	M	
660	2.67	45	1.5	C	250	6	2	300	10	0	M	
661	2.67	45	1.5	C	250	6	2	300	10	0	M	
662	2.67	35	1.5	F	250	6	2	300	10	0	M	
663	2.67	35	1.5	F	250	6	2	300	10	0	M	
664	2.67	35	1.5	F	250	6	2	300	10	0	M	
	Franklin County (a)—											
665	8.7	45	1.5	C	250	6	2	300	10	0	M	6.6.
666	8.7	45	1.5	C	250	6	2	300	10	0	M	11.5.
667	8.7	45	1.5	C	250	6	2	300	10	0	M	
668	8.7	45	1.5	C	250	6	2	300	10	0	M	
669	8.7	45	1.5	C	250	6	2	300	10	0	M	
670	8.7	35	1.5	F	250	6	2	300	10	0	M	
671	8.7	35	1.5	F	250	6	2	300	10	0	M	
672	8.7	35	1.5	F	250	6	2	300	10	0	M	

(*) 45 grams = 0.1 pound.

(†) 300° C. = 572° F.

(‡) In the tables the strength of a briquet is referred as poor (P), medium (M), and good (G). A poor briquet is defined as one which has cracks although it remains whole after removal from die. A medium briquet is free from cracks but proves weak when submitted to tumbling or shattering tests. A good briquet has high mechanical strength as evidenced by less than 5 per cent loss when tumbled two for minutes. The absence of the formation of a briquet is indicated by a dash (—).

TABLE 9—Continued

Test number	County and moisture	Amount (grams) (*)	Diameter of die (inches)	Shape of die	Weight of hammer (pounds)	Height of drop (feet)	No. of impacts	Temperature, ° C. (†)	Preheating in die (minutes)	Preheating in oven (minutes)	Briquet (‡)	Loss of weight, percent (tumbling). Remarks
	Perry County (a)—											
673	9.0	45	1.5	C	250	6	2	300	10	0	M	7.2.
674	9.0	45	1.5	C	250	6	2	300	10	0	M	5.7.
675	9.0	45	1.5	C	250	6	2	300	10	0	M	
676	9.0	45	1.5	C	250	6	2	300	10	0	M	
677	9.0	45	1.5	C	250	6	2	300	10	0	M	
678	9.0	35	1.5	F	250	6	2	300	10	0	M	
679	9.0	35	1.5	F	250	6	2	300	10	0	M	
	Macoupin County (a)—											
680	12.5	45	1.5	C	250	6	2	300	10	0	G	4.9.
681	12.5	45	1.5	C	250	6	2	300	10	0	G	3.2.
682	12.5	45	1.5	C	250	6	2	300	10	0	G	
683	12.5	45	1.5	C	250	6	2	300	10	0	G	
684	12.5	45	1.5	C	250	6	2	300	10	0	G	
685	12.5	35	1.5	F	250	6	2	300	10	0	M	
686	12.5	35	1.5	F	250	6	2	300	10	0	M	
	Williamson County (a)—											
687	7.7	45	1.5	C	250	6	2	300	10	0	P	13.3.
688	7.7	45	1.5	C	250	6	2	300	10	0	P	Broke.
689	7.7	45	1.5	C	250	6	2	300	10	0	P	
690	7.7	45	1.5	C	250	6	2	300	10	0	P	
691	7.7	45	1.5	C	250	6	2	300	10	0	P	
692	7.7	35	1.5	F	250	6	2	300	10	0	P	
	Saline County—											
693	6.2	45	1.5	C	250	6	2	300	10	0	G	4.4.
694	6.2	45	1.5	C	250	6	2	300	10	0	G	4.8.
695	6.2	45	1.5	C	250	6	2	300	10	0	G	

696	6.2	45	1.5	C	250	6	2	300	10	0	G	
697	6.2	45	1.5	C	250	6	2	300	10	0	G	
698	6.2	50	1.5	C	250	6	2	300	10	0	—	Die trouble.
699	6.2	50	1.5	C	250	6	2	300	10	0	—	Die trouble.
700	6.2	50	1.5	C	250	6	2	300	10	0	P	
701	6.2	50	1.5	C	250	6	2	300	10	0	P	
	Franklin County (d)—											
702	8.7	45	1.5	C	250	6	2	300	10	0	M	6.5.
703	8.7	45	1.5	C	250	6	2	300	10	0	M	10.0.
704	8.7	45	1.5	C	250	6	2	300	10	0	M	
705	8.7	45	1.5	C	250	6	2	300	10	0	M	
706	8.7	45	1.5	C	250	6	2	300	10	0	M	
707	8.7	35	1.5	F	250	6	2	300	10	0	M	
708	8.7	35	1.5	F	250	6	2	300	10	0	—	
709	8.7	35	1.5	F	250	6	2	300	10	0	M	
710	8.7	50	1.5	C	250	6	2	200	10	0	—	
	Perry County (b)—											
711	8.7	45	1.5	C	250	6	2	300	10	0	M	8.5.
712	8.7	45	1.5	C	250	6	2	300	10	0	P	11.8.
713	8.7	45	1.5	C	250	6	2	300	10	0	M	
714	8.7	45	1.5	C	250	6	2	300	10	0	M	
715	8.7	45	1.5	C	250	6	2	300	10	0	M	
716	8.7	35	1.5	F	250	6	2	300	10	0	M	
717	8.7	35	1.5	F	250	6	2	300	10	0	M	
	Franklin County (b)—											
718	8.1	45	1.5	C	250	6	2	300	10	0	M	10.5.
719	8.1	45	1.5	C	250	6	2	300	10	0	M	11.5.
720	8.1	45	1.5	C	250	6	2	300	10	0	M	
721	8.1	45	1.5	C	250	6	2	300	10	0	M	
722	8.1	45	1.5	C	250	6	2	300	10	0	M	
723	8.1	35	1.5	F	250	6	2	300	10	0	P	
724	8.1	35	1.5	F	250	6	2	300	10	0	P	
	Franklin County (d)—											
725		40	1.5	C	500	5	1	300	0	30	P	16.12.
726		40	1.5	C	500	5	1	300	0	20	P	13.0.
727		40	1.5	C	500	5	1	300	0	10	M	7.48.

(*) 45 grams = 0.1 pound.
(†) 300° C. = 572° F.
(‡) In the tables the strength of a briquet is referred as poor (P), medium (M), and good (G). A poor briquet is defined as one which has cracks although it remains whole after removal from die. A medium briquet is free from cracks but proves weak when submitted to tumbling or shattering tests. A good briquet has high mechanical strength as evidenced by less than 5 per cent loss when tumbled two for minutes. The absence of the formation of a briquet is indicated by a dash (—).

TABLE 9—Concluded.

Test number	County and moisture	Amount (grams) (*)	Diameter of die (inches)	Shape of die	Weight of hammer (pounds)	Height of drop (feet)	No. of impacts	Temperature, ° C. (†)	Preheating in die (minutes)	Preheating in oven (minutes)	Briquet (‡)	Loss of weight, percent (tumbling). Remarks
	Franklin County (d)—Concluded											
728		40	1.5	C	500	4.5	1	300	0	10	G	1.33 Float 2.72.
729		40	1.5	C	500	4.5	1	300	0	10	G	1.33 Float 2.72.
730		40	1.5	C	500	5	1	300	0	0	—	
731		40	1.5	C	500	5	1	200	0	30	M	7.32.
732		40	1.5	C	500	5	1	200	0	20	M	9.2.
733		40	1.5	C	500	5	1	200	0	10	—	
	Franklin County (b)—											
734		40	1.5	C	500	4.5	1	300	0	10	P	14.0.
735		40	1.5	C	500	4.5	1	200	0	10	—	Die trouble.
736		40	1.5	C	500	4.5	1	200	0	10	G	4.65 Tight plunger.
737		40	1.5	C	500	4.5	1	300	0	10	G	1.33 Float; 3.72.
738		40	1.5	C	500	4.5	1	300	0	10	G	1.33 Float; 2.9.
	Williamson County (a)—											
739		40	1.5	C	500	4.5	1	300	0	10	P	21.1.
740		40	1.5	C	500	4.5	1	300	0	10	G	5.47.
741		45	1.5	C	500	4.5	1	200	0	10	M	9.96 Tight plunger.
	Perry County (b)—											
742		40	1.5	C	500	4.5	1	300	0	10	P	1.80.
743		40	1.5	C	500	4.5	1	300	0	10	G	1.33 Float; 2.40.
744		40	1.5	C	500	4.5	1	300	0	10	G	1.33 Float; 2.96.
745		45	1.5	C	500	4.5	1	200	0	10	—	Die trouble.
746		45	1.5	C	500	4.5	1	200	0	10	G	4.43 Tight plunger.

	Franklin County (a)—											
747	....	40	1.5	C	500	4.5	1	300	0	10	P	14.7.
748	....	40	1.5	C	500	4.5	1	300	0	10	G	3.3 Tight plunger.
749	....	40	1.5	C	500	4.5	1	200	0	10	—	Die trouble.
750	....	40	1.5	C	500	4.5	1	200	0	10	M	
751	Perry County (a)	40	1.5	C	500	4.5	1	300	0	10	G	5.72.
752	Saline County	40	1.5	C	500	4.5	1	300	0	10	G	1.63.
753	Macoupin County (a)	40	1.5	C	500	4.5	1	300	0	10	M	5.97.
754	Will County	40	1.5	C	500	4.5	1	300	0	10	G	2.15.
755	Jackson County	40	1.5	C	500	4.5	1	300	0	10	G	2.69.
	Calhoun County—											
756	....	40	1.5	C	250	6	2	300	10	0	G	
757	....	40	1.5	C	500	4.5	1	300	0	10	G	1.87
	Macoupin County (b)—											
758	....	40	1.5	C	250	6	2	300	10	0	G	
759	....	40	1.5	C	500	4.5	1	300	0	10	G	2.14
	St. Clair County—											
760	....	40	1.5	C	250	6	2	300	10	0	G	
761	....	40	1.5	C	500	4.5	1	300	0	10	G	1.34 All float on 1.3.
	Montgomery County—											
762	....	40	1.5	C	250	6	2	300	10	0	G	
763	....	40	1.5	C	500	4.5	1	300	0	10	G	1.37
764	Saline County	40	1.5	C	250	6	2	300	10	0	G	
765	Franklin County (a)	40	1.5	C	250	6	2	300	10	0	G	
766	Williamson County (b)	40	1.5	C	500	4.5	1	300	0	10	G	2.35
767	Washington County	40	1.5	C	500	4.5	1	300	0	10	G	1.60
768	Perry County (c)	40	1.5	C	500	4.5	1	300	0	10	G	2.44
769	Randolph County	40	1.5	C	500	4.5	1	300	0	10	G	1.63
	Sangamon County (-4 mesh)—											
770	7.75	45	1.5	C	500	4.5	1	300	0	10	G	1.26.
771	5.40	45	1.5	C	500	4.5	1	300	0	10	G	1.47.
772	9.70	45	1.5	C	500	4.5	1	300	0	10	G	1.24.
773	0.82	45	1.5	C	500	4.5	1	300	0	10	G	1.63.

(*) 45 grams = 0.1 pound.
(†) 300° C. = 572° F.
(‡) In the tables the strength of a briquet is referred as poor (P), medium (M), and good (G). A poor briquet is defined as one which has cracks although it remains whole after removal from die. A medium briquet is free from cracks but proves weak when submitted to tumbling or shattering tests. A good briquet has high mechanical strength as evidenced by less than 5 per cent loss when tumbled two for minutes. The absence of the formation of a briquet is indicated by a dash (—).

CHAPTER V.—FUTURE INVESTIGATIONS

The demonstration of the possibility of making a good briquet from Illinois coal without a binder, even by laboratory method, represents a distinct step toward providing from Illinois coal a more satisfactory fuel for the discriminating user. The briquets themselves are the best evidence that the investigation has been a profitable one. There is, however, need of further substantiation of certain incomplete conclusions that have been reached and in addition, need to determine the limitations of the proposed procedure. Desirable lines of investigation may be briefly indicated.

DETERMINATION OF EFFECT OF VARYING QUANTITIES OF MINERAL MATTER ON BRIQUETS PRODUCED BY THE IMPACT PROCESS

Inasmuch as it is anticipated that the briquetting process requires fine coal, it is anticipated that its successful adaptation will result in the use of the fine sizes or screenings in the making of briquets. It is, therefore, important to determine the limiting conditions with respect to mineral matter content. The tests described indicate that the best briquets are formed from clean coal and it is quite probable that there is a definite limit to the amount of ash that a good briquet may contain. It is of course evident that the value of any briquet will be determined very largely by its ash content and hence only clean coal should be used in their fabrication.

DETERMINATION OF EXACT LIMITS OF CONTROLLING VARIABLES

Although the combination of conditions that has been selected as most favorable seems to be well adapted to most Illinois coals, it is not wise to entirely neglect the possibility that slight variation in conditions may be necessary for certain coals with which difficulty is experienced. By no means all varieties of coal found in Illinois have been tested. In this connection it is desirable to continue systematic tests to determine the exact limits of the controlling variables, pressure, temperature, time, weight of coal, size of coal, and size of die.

DETERMINATION OF PHYSICAL AND CHEMICAL CAUSES OF COMPACTION

Until the causes of comparison are understood, experimentation proceeds more or less uncertainly. Microscopic investigations of polished surfaces and thin sections will possibly throw light on the physical nature of compaction. Additional chemical analyses will be necessary before it can be definitely known whether the compaction process affects the rank of the coal.

STUDIES OF THE EFFECT OF TIME AND EXPOSURE UPON THE BRIQUETS

One of the outstanding problems in connection with the briquetting of Illinois coal at this stage is the determination of the effect of time and exposure upon the briquet. It is desirable to know whether the briquet reabsorbs moisture upon exposure in a manner similar to that of coal. If so they will probably weather like coal, and deteriorate fairly rapidly. If not, and particularly will this be true of the high moisture coal, the briquet will be a fuel considerably superior to the raw coal from which it is formed.

BURNING CHARACTERISTICS OF THE BRIQUET

Investigation is desirable concerning the burning characteristics of the briquet under conditions similar to those in which it will probably have its greatest use.

SYSTEMATIC TESTS OF A VARIETY OF COALS

The selected process for impaction requires further testing of a larger number of Illinois coals with some quantitative determination of the percentage of successful results either in the terms of percentage of successful briquets formed in attempts made, or in terms of quantity of briquets derived from a given quantity of coal. It is believed that these tests are desirable if for no other reason than to supply a better substantiation of the suitability of the proposed laboratory procedure than is furnished by the evidence supplied by this report.

TESTS UPON FINE COALS AND COAL DUSTS

A special series of tests is desirable to determine possible modification of the procedure necessary to accomplish briquetting of very fine size grade of coals such as are produced particularly by dedusting plants. A few tests made in connection with the present series indicated that dusts did not readily yield favorably to the proposed briquetting process. Special investigation will probably be necessary to determine whether adjustments to the conditions can be made that will result in forming good briquets from such material.

COMMERCIAL TESTS OF THE IMPACT PROCESS

Eventually it seems probable the possibility of commercial adaptation of the laboratory method of briquetting Illinois coal by impact will receive attention. Additional experimentation may or may not be necessary to convince operators and engineers that the conclusions reached in this report of investigation are valid and significant. Any such experiments should certainly be preceded by investigations already suggested—particularly as concerns the effect of mineral matter in the coal, the effect of weathering upon the briquet, and the burning characteristics of the briquet.

BIBLIOGRAPHY

The following bibliography on briquetting is restricted almost entirely to titles relating to the problem of briquetting bituminous coals and coals of higher rank. A few articles that describe processes of briquetting brown coals or lignites are included because of their particular interest in connection with the present problem, but no attempt has been made to list all titles which concern the briquetting of coal below bituminous rank:

1—Alford, N. G., and Prostel, E., "Briquettes from carbonized lignite." Min. Cong. J. *17*, 194-7 (1931).
Describes lignite carbonized at 600° C. for 16 hours, then briquetted with 8 per cent binder.

2—Babcock, E. J., "Production and briquetting of carbonized lignite." U. S. Bur. Mines Bulletin 221 (1923).
Summarizes various tests made upon briquets of carbonized lignite residue.

3—Balph, J., and McQuade, M. J., "Low temperature carbonization of coal by the Hayes process." 2nd Inter. Coal Conf. *1*, 269 Nov. (1928).
Slack coal is passed through low temperature carbonization, the residue being briquetted with pitch as a binder.

4—Benson, H. K., Borglin, J. N., and Rourke, R. K., "Effect of sulphur in the briquetting of sub-bituminous coal." Ind. and Eng. Chem., *18*, 116-17 (1926).
The presence of sulphur in carbonized briquets made with asphalt binder gives greater strength.

5—Berl, E., "Formation of bituminous coal." Colliery Guardian *144*, 914-16 (1932).
Claims that formation and parent substances of bituminous and of brown coals are not the same.

6—Berthelot, C., "Recent European progress in technique of coal carbonization." Proc. 3rd Inter. Conf. Bit. Coal *1*, 495-6 (1932).
Anthracite fines are briquetted with 7 per cent pitch and carbonized at 930° C. for 8 hours to give a product of 0.84 density and a strength of 250-300 kilograms per square centimeter.

7—Berthelot, C., "Les methodes modernes de carbonisation a basse temperature et de preparation d'anthracite artificiel." Chemie & Ind. *29*, 18-44 (1933).
Correlates theory of low temperature carbonization with successful commercial installations.

8—Berthelot, M. C., "The Beneficiation of non-coking coals." Colliery Guardian *144*, 1147-8 (1932).
Discusses the disposal of fine coals by briquetting.

9—Bing, J., "Briquetting." Chaleur ind. *9*, 21-9 (1928).
Briquetting dry coal by heat and pressure, using pitch as a binder.

10—Bloedel, R. F., "Make 'Coalettes' out of slack, turn loss into profit." Coal Heat *22*, 17, Dec. (1932).
A Wisconsin briquetting plant finds operation profitable and demand increasing.

11—Blum, I. L., "Role of Humic Acids in briquetting of brown coal." Proc. of 3rd Intern. Conf. Bit. Coal *2*, 646-666 (1931).

States amounts of humic acid and water required for briquetting brown coal.

12—Bode, H., "Die Inkohlung eine Druckuerschwelung?" Angewandte Chemie *45*, 388-90 (1932).

Describes a series of briquetting tests made upon cellulose, recent woods, decayed woods, peat, lignites, and brown coals without use of a binder.

13—Bode, H., "Die petrographische Untersuchung von Steinkohlenbriketts," Brennstoff-Chemie *11*, 478-8 (1930); *12*, 7-9 (1931).

Gives analysis of grain composition, pitch distribution, influence of fusain content on strength of briquets and petrographic composition of Westphalian briquetting coals.

14—Born, G., "Steinkohlenteerpech als Bindemittel fur Steinkohlenbriketts." Gluckauf *68*, 688-92 (1932).

Discusses theory of binders and says that the physical state of the material to be briquetted (size of grains, character of surfaces) has an equally important bearing on nature of briquets.

15—Brownlie, D., "Low temperature carbonization (Duryea and White)." Proc. S. Wales Inst. Eng. *42*, 349 (1926).

Duryea and White presses were used to briquet without binder pulverized raw coal at pressures of 16,000 to 20,000 pounds per square inch. The briquets were afterwards carbonized.

16—Brownlie, D., "Low temperature carbonization (Dobbelstein)." Proc. S. Wales Inst. Eng. *42*, 348 (1926).

Briquets for subsequent carbonization were made without binder from mixtures of fine coal and coke dust by heating to incipient plasticity and compressing at 60,000 to 75,000 pounds per square inch.

17—Brownlie, D., "Low temperature carbonization (Delkeskamp)." Proc. S. Wales Inst. Eng. *42*, 369 (1926).

By use of raw fuel ground up with water into a colloidal solution as a binder briquets for carbonization were formed at steam temperature by application of pressures of 2,000 to 4,000 pounds per square inch.

18—Brownlie, D., "Low temperature carbonization in Germany." Iron and Coal Trades Review *119*, 939-40 (1929).

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Two Hardy processes are described, one of which heats bituminous coal smalls at 550° C. for 2¾ hours in tightly covered trays, the other of which heats bituminous coal smalls to 350-400° C., compresses them in a roll press, and carbonizes the product.

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24—CURTIS, H. A., "Low temperature carbonization of coal and manufacture of smokeless fuel briquettes." Chem. & Met. Eng. *23*, 499-501 (1920).
Describes plant of Carbocoal process and compares low temperature and high temperature carbonization.

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26—DAMM, P. and WESEMAN, F., "Verwendungsmöglichkeiten und Bewertung des Koksgruses in Oberschlesien." Stahl und Eisen, *50*, 1495-1500 (1930).
Gives in detail the economics of the use of coke dust for briquetting and other purposes.

27—DAVIDSON, E. W., "Toledo plant makes Trent amalgam better known." Coal Age *27*, 139-42 (1925).
Pulverized coal slack is washed and briquetted with an oil binder.

28—DAVIS, C. A., "Production and use of brown coal in vicinity of Cologne, Germany." U. S. Bureau of Mines Tech. Paper *55*, (1913).
Describes process by which briquets are made from brown coal without the use of a binder.

29—DAVIS, J. C., "Some investigations in briquetting Oklahoma coal." Chem. & Met. Eng. *23*, 101-102 (1920).
A binder of crude oil gave briquets which stood three drops of five feet each with only 1 per cent loss in weight.

30—DROEGE, A., "Ein neues Verfahren der Steinkohlenbrikettierung unter Verwendungt, von feüssigem Pech." Gluckauf *57*, 1093 (1921).
Describes briquets made of anthracite coal, using liquid pitch as a binder.

31—DUPUY, H., "Manufacture of lump fuels agglomerated by heating." Chaleur ind *9*, 292-3 (1928).
Mixed lean and fat coals are briquetted with pressure and heat.

32—EPPERLY, L., "Mine briquette plant concentrates on one coal to achieve uniformity in quality." Coal Age *37*, 15-16 (1932).
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51—Kayser, J., "Briquetting of coke breeze." J. Soc. Chem. Ind. *38*, 34-5 A (1919).
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54—King, T. A., "Sand-lime brick manufacturers discuss products and costs. Coal-cement briquettes as a sideline." Rock Prod. *34*, 73-4 (1931).
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55—Kneeland, F. H., "Plant in Newark makes briquets by Trent process." Coal Age, *26*, 715-16 (1924).
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56—Léaute, A., and DuPont, G., "Partial dehydrogenation of fine coal to permit of its briquetting." Mech. Eng. *50*, 855-6 (1928).
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57—Levy, G., "Essai sur l'auts agglomeration de la houille." Revue de l'industrie minerale *12*, 43 (1932).
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58—Lloyd, S. J., "Low-temperature carbonization of coal." Am. Gas J. *114*, 353-4 (1921).
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59—Malcolmson, C. T., "Carbocoal, smokeless fuels from high volatile coals." Am. Inst. Min. Eng. Bull. *137*, 971-7 (1918); Iron Tr. R. *63*, 496-7 (1918); Am. Inst. Min. Eng. Bull. *142*, 1533-42; *143*, 1686-92 (1918).
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60—Malcolmson, C. T., "Briquetted coal and its value as a railroad fuel." Proc. First Ann. Convention Inter. Ry. Fuel Assoc. (1909).
Historical sketch; tests on briquets made with pitch and asphalt binders.

61—McGraw, J. B., "Ontario establishes another plant for briquetting anthracite fines with crude-oil residuum." Coal Age *21*, 403-6 (1922).
Briquets made in a Belgium roll press at high temperature and pressure. Crude oil is used as a binder.

62—McIntire, C. V., and Thomson, L. R., "Low-temperature semi-coke in briquetted form." Ind. and Eng. Chem. *19*, 12-15 (1927).
Low-temperature semi-coke briquetted with a coal tar pitch binder, then carbonized.

63—McKenney W. F., "Fuel briquettes." U. S. Bureau of Mines, Mineral Res. of U. S. Pt. 2, 187-92 (1924).

Average value of briquets per ton in 1924 was $8.59. Most common binder used was asphaltic pitch. There were but two plants, briquetting carbon residue, which used no binder.

64—Nagel, T., "Binding compound makes satisfactory briquettes." Coal Age *31*, 262-3 (1927).

Briquets for subsequent carbonization are made using as a binder phosphoric acid mixed with carbohydrate adhesives.

65—Nagel, T., "Low-volatile coal, if satisfactorily briquetted, makes excellent domestic fuel." Coal Age *31*, 638-40 (1927).

Low-volatile bituminous slack was briquetted with a phosphoric acid binding compound and a fuel the equivalent of anthracite was produced.

66—Napier, J. W., "Solid smokeless fuel." Gas J. 201, 264-6 (1933).

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67—Nielson, H., "Carbonized briquets." Gas Journal *194*, 613-14 (1931).

Briquets are made from anthracite duff and semi-coke with a low-temperature pitch binder, then subjected to a high-temperature carbonization.

68—Odell, W. W., "Lignite carbonization—carbonized residue briquets." Chem. and Met. Eng. *26*, 207-8 (1922).

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69—Parr, S. W. and Olin, H. L., "The coking of coal at low-temperature." Univ. of Ill. Eng. Exp. Sta., Bull. 60, 22. (1912).

Attempts were made to briquette moistened, powdered mixtures of coke breeze and coal in a hand press at a pressure of 1,000 pounds per square inch. The resulting briquets disintegrated upon being subjected to carbonization.

70—Smith, C. M., "An investigation of the friability of different coals." Univ. of Ill. Eng. Exp. Sta. Bull. *196* (1929).

Gives results of series of drop tests on wood, steel, and cement.

71—Stach, H., "Uber die Metamorphose der Kohlen und das Problem der kunstlicken Inkohlung." Braunkohle *31*, 912-18 (1932).

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72—Stansfield, E., "Alberta experiments in making briquettes from coal dust hitherto wasted." Coal Age *26*, 544 (1924).

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73—Stansfield, E., Lang, W. A., Gilbart, K. C., Brewer, R. G., Teskey, M. F., Morris, H. E., Twelfth Annual Report of Research Council of Alberta. *17* (1931).

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74—Stansfield, E., and Lang, W. A., "Principles in the briquetting of coking and non-coking bituminous coals." Proc. 2nd Inter. Conf. Bit. Coal *1*, 508-26 (1928).

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75—Stevens, J. E., "Factors to be borne in mind in making briquets of fine materials." Coal Age *19*, 663-6 (1921).

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76—STILLMAN, A. L., "Briquetting." (1923).
Gives history of briquetting industry with special emphasis on briquetting in United States.

77—STILLMAN, A. L., "Toronto is briquetting river anthracite." Coal Age *17*, 929-33 (1920).
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78—SUTCLIFFE, E. R., and EVANS, E. C., "Low- versus high-temperature carbonization for the production of smokeless fuel." Iron and Coal Tr. R. *104*, 607 (1922). Proc. S. Wales Inst. Eng. Vol. 42 (1926).
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79.—SWIETOSLAWSKI, W., and ROGA, B., and CHORAZY, M., "Briquetting of coal slack without use of binder." Fuel in Science and Practice *9*, 421-39 (1930).
Results of investigations on briquetting fine coal mixtures under combined pressure-temperature-time conditions.

80—TERRES, E., "Contributions to the origin of coal and petroleum." Proc. 3rd Inter. Conf. Bit. Coal *2*, 797-808 (1932).
Summary of experimental work from which author arrived at conclusion that bituminous coal cannot come from brown coal, but comes from a different parent substance.

81—(THARSIS SULPHUR & COPPER CO.) "A briquetting plant in South Wales." Eng. & Min. J. *95*, 945 (1913).
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82—THAU, A., "Plunger of low-temperature carbonizing retort expels product as bar, knife slicing off briquets." Coal Age *20*, 913-14 (1921).
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83—TREPTOW, E., "Grundzüge der Bergbaukunde, einschliesslich Aufhereitung und Brikettieren." (1925).
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84—UBALDINI, I, and SINIRAMID, C., "Carbonization of newly formed lignites." Ann. Chim. Applicata *22*, 175-93 (1932).
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85—ULOTH, R., and SWIETOSLAWSKI, W., "Fur Frage der Brikettierung von Steinkohlenstaub ohne Bindemittel." Zeit des Oberschlesischen Berg-und Huettenmaennichen Verein zu Katowice *69*, 244-254 (1930).
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86—VERTU, L., "The solution to the problem of the manufacture of pressed coal from coal dust." Industria chimica *4*, 567-9 (1929).
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87—VERTU, L., "The process of agglomeration cracking." Industria chimica *6*, 276-7 (1931).
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88—WEISE, E., "Zuer Frage des Pechersatzes in der Steinkohlenbrikettierung." Montanistische Rundschau *21*, 365-372 (1929).
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90—WHIPPERMAN, F., "Make 'coal bricks' out of the slack and sell it at a good price—a profit." Coal Heat, *22*, 7, Aug. (1932).
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92—YOUNG, W. H., "Fuel briquettes in 1931." U. S. Bureau of Mines, Mineral Res. of U. S., 1931, pt. 2, 61-71, (1932).
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95—"Production of fuel briquets in 1928." Power Pl. Eng. *33*, 515 (1929).
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96—"Coal flotation and briquetting of float makes rapid strides in many countries." Coal Age *22*, 485 (1923).
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PATENTS

1—O'DONNELL, J. F., U. S. Patent 1,557,320, Oct. 13, 1926.
Equal amounts of fine anthracite and semi-bituminous coal dust are mixed with each other, molded under pressure and subjected to a temperature of 540° C. for 5 to 6 minutes.

2—HARDY, H., Brit. Patent 357,330, Feb. 8, 1930.
Coal fines are heated to a temperature just below the plastic stage (300-400° C.), briquetted in a roll press, and carbonized.

3—HARDY, H., Brit. Patent 317,374, Aug. 14, 1928; Brit. Patent 318,520, Sept. 4, 1928.
Bituminous coal smalls are carbonized at temperatures up to 550° C. in shallow trays divided into cubes and containing perforated covers.

4—O'DONNELL, J. F., Brit. Patent 247,272, Nov. 10, 1924.
Mixtures of anthracite birdseye coal and anthracite dust coal and bituminous coal are pressed and heated to 800-1000° C. for 3 to 6 minutes in a perforated container.

5—HOFMANN, F., HEYN, M., GROTE, W., and DUNKEL, M., German Patent 455,015.
Process for briquetting coal dust by pressing it in hot condition.

6—DUNKEL, M., German Patent 458,247.
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7—HARDY, H., Belgium Patent 365,781, Dec. 31, 1929.
Coal fines are heated to a temperature just below the plastic stage (300-400° C.), briquetted in a roll press, and carbonized.

8—HARDY, H., Belgium Patent 353,484, Sept. 30, 1928.
Bituminous coal fines are carbonized at temperatures up to 550° C. in shallow trays divided into cubes and containing perforated covers.